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GREAT MIAMI AQUIFER VAM3D FLOW MODEL RE-CALIBRATION

FERNALD ENVIRONMENTAL MANAGEMENT PROJECT
FERNALD, OHIO

MAY 2000

U.S. DEPARTMENT OF ENERGY
FERNALD AREA OFFICE

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EXECUTIVE SUMMARY

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The Great Miami Aquifer groundwater flow and transport model for the Fernald site was calibrated in 1993 with the Sandia Waste Isolation Flow and Transport (SWIFT) modeling code. The SWIFT groundwater model was developed to support the Operable Unit 5 Remedial Investigation and Feasibility Studies (RI/FS) which were just beginning. Because the model was designed to support the risk assessment studies in the RI/FS, it is very conservative. While the SWIFT model was appropriate for the purposes of the RI/FS modeling studies, it was not adequate for tracking and predicting details of the aquifer remedy performance.

A groundwater modeling upgrade project was begun in 1998 to provide a model capable of tracking and predicting details of the aquifer remedy performance by implementing newer modeling technologies [illegible] since the SWIFT code was written in the late 60's and early 70's. This upgrade is transitioning the site groundwater model to the VAM3D code developed by HydroGeoLogic, Inc. The first phase of this transition has been completed and a report was published detailing the model improvements in Phase I (HydroGeoLogic, July 1998). One of the requirements of the second phase of the upgrade project (which incorporates data fusion principles into the transport model) was an improved flow model calibration.

The first phase of the aquifer remedy for the Fernald site was implemented in 1998 with significant pumping and re-injection in the aquifer. After pumping and re-injection began, differences between the 1993 calibrated model flow predictions and flow patterns inferred from measured groundwater elevations were observed in some areas of the site. A model re-calibration was necessary to provide model flow predictions that more closely match groundwater flows inferred from the field data.

The VAM3D groundwater flow model has been re-calibrated and flow predictions now match inferred flows from measured groundwater elevation data. This report presents the re-calibration criteria and methodology in Section 2, and discusses the calibration results in Section 3.

The VAM3D flow model was re-calibrated to match October 1998 groundwater monitoring well elevation data. These data were collected after the South Field Phase I Extraction System, the South Plume Optimization Wells, and the Re-Injection Demonstration System began operating in July, August, and September 1998 respectively. Model re-calibration was accomplished by making corrections to fixed head boundary conditions at model edges and by adjusting surface water infiltration rates at the model surface. As discussed in the report, changes to aquifer characteristics (i.e. hydraulic conductivity and porosity) were not required for this re-calibration.

After a successful flow calibration, the flow model was validated against an April 1998 groundwater elevation data set. The results of this initial validation, which are discussed in Section 4, were not as successful as the calibration effort because the April 1998 groundwater elevation data were collected during one of the wettest periods in recent history and only a day or two after a significant rainfall event in the area. As discussed in the report, it is believed that transient flow phenomena are present in the April 1998 data, which can not be faithfully reproduced by a steady state groundwater model.

A second set of model validation runs were made and compared against groundwater elevation data collected in July 1998, and October 1999. These validation results were more successful than the attempt to validate against the April 1998 data set, and the results are in close agreement with the model calibration against the October 1998 data. These additional model runs and results are discussed in Appendix D.

In conclusion, the VAM3D groundwater flow model has been successfully calibrated against the October 1998 groundwater elevation data and validated against July 1998, and October 1999 groundwater elevation data. In both calibration and validation efforts, model results were made to match measured elevation data within the established criteria by changing model boundary heads and model infiltration rates. Changes to aquifer conductivities or porosities (set in the 1993 SWIFT model calibration) were not required in this most recent calibration effort.

1.0 INTRODUCTION

The previous FEMP Great Miami Aquifer steady-state flow model used the SWIFT modeling code and was calibrated to June 1993 water elevation data (Parsons, 1994). This calibrated model was recently converted to the VAM3D modeling code (HydroGeoLogic 1998) to improve uranium transport simulations. A project is currently underway to couple the VAM3D code with Data Fusion Modeling (DFM) techniques. DFM will improve the groundwater model by allowing timely incorporation of monitoring data to set modeling parameters for more accurate transport predictions.

An updated steady-state flow model, calibrated to data more recent than June 1993, is desirable for the following reasons: 1) Aquifer stresses have changed significantly since June 1993, with the addition of 3500 gpm of new pumping (South Plume Extraction System and South Field Extraction System) and 1000 gpm of re-injection (Re-injection Demonstration System); 2) Groundwater elevation data indicate flow directions near the southeast corner of the site are not in agreement with predicted flow directions from the model; and 3) The incorporation of DFM with the VAM3D model requires a good steady-state flow solution as input in order to provide a robust transport model.

A two-stage approach was used to re-calibrate the flow model. First, the model was re-calibrated to a recent set of groundwater elevation measurements, which included the effects of all currently operating pumping/re-injection systems. The second stage was to check the re-calibrated model by validating it against a second set of water elevation measurements which represented more extreme aquifer conditions. A robust, calibrated model should produce reasonable predictions of groundwater elevations over the range of conditions to be encountered in the aquifer.

The two-stage, calibration/validation approach is designed to verify that parameters that remain constant (i.e., hydraulic conductivity, porosity) in spite of changing aquifer conditions are accurately estimated in the final calibrated model. For steady-state flow models, the constant parameters are typically the components of hydraulic conductivity for the various model materials. Other parameters, such as specified-head and specified-flux boundary conditions, typically change with aquifer stresses and water elevations, and different values must be used for calibration and validation. For example, compared to the data set used to re-calibrate the model, validation data were gathered from a period of time when precipitation and aquifer water elevations were much higher and pumping conditions were different. Therefore, different net recharge, pumping, injection, and specified-head boundary conditions must be used for validation to correctly test the calibrated hydraulic conductivity distribution. Boundary conditions may be specified (for example, known pumping and injection locations and rates); estimated from other modeling techniques (net surface recharge rates are commonly obtained this way); estimated from nearby measurements; or determined as part of the calibration or validation procedure if nearby measurements are not available.

If the validation procedure indicates that the calibrated hydraulic conductivity distribution needs to be changed, the calibration/validation procedure must be repeated with revised conductivity estimates until a satisfactory distribution is obtained. A satisfactory conductivity distribution should agree with field test results, and produce as close a fit as possible between modeled and measured water levels for both calibration and validation conditions.

2.0 STEADY-STATE FLOW MODEL RE-CALIBRATION AND VALIDATION PROCEDURES

The steady-state flow model re-calibration was performed first, followed by validation. For both calibration and validation phases, the following steps were executed: 1) Select target groundwater elevation data; 2) Adopt calibration/validation criteria; 3) Develop a function (typically called the objective function) to quantify the agreement between modeled and target water elevations as successive model runs are executed; 4) Perform an initial run by modifying modeled pumping/re-injection rates as necessary to reflect conditions for the period simulated; and 5) Iteratively execute the model, making incremental changes in model parameters until the calibration/validation criteria are met or until the objective function can no longer be significantly decreased.

For purposes of this report step 5 in the above procedure has slightly different meanings for calibration and validation. For calibration, incremental changes were made to both hydraulic conductivity and boundary conditions. For validation, which represents much different aquifer conditions, incremental changes were made to boundary conditions only. Hydraulic conductivities should be independent of water elevations and aquifer stress conditions. If a validation procedure results in a poor fit between modeled and measured results (i.e. groundwater elevations), and sensitivity analyses show the fit can be significantly improved with different conductivities, the appropriate conductivity changes should be made (consistent with field observations) and the calibration/validation procedure should be repeated. The calibration/validation procedure is summarized in Figure 2-1

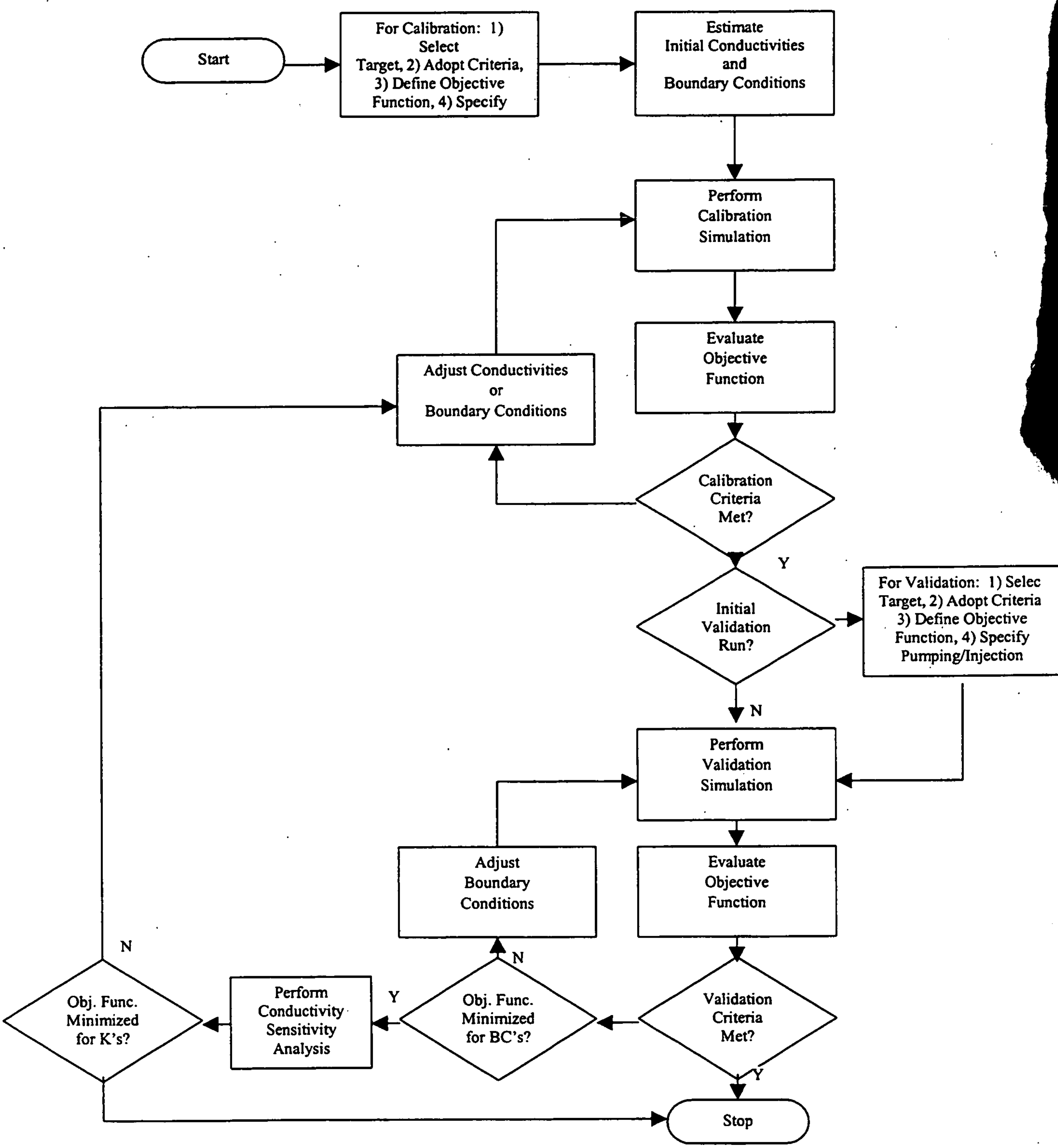

FIGURE 2-1 FLOWCHART OF CALIBRATION/VALIDATION PROCEDURE.

3.0 STEADY-STATE FLOW MODEL RE-CALIBRATION

3.1 CALIBRATION TARGET

To select a calibration target, available groundwater elevation data were surveyed to determine the most complete set gathered during current pumping conditions, including operation of all South Plume, South Field, and Re-injection Demonstration wells. The October 1998 groundwater elevation data set was chosen as the calibration target. This data set was especially appropriate for calibration because it had moderate groundwater elevations compared to historical extremes. Data taken during the autumn months, when extreme precipitation events are less frequent, are more likely to represent a true steady-state condition. Figure 3-1 shows the October 1998 groundwater elevations chosen as the calibration target. The October 1998 calibration data set is included in Table 1 of Appendix A.

3.2 CALIBRATION CRITERIA

The same calibration criteria as those used in the June 1993 SWIFT calibration were chosen for the re-calibration. The two main criteria are: 1) The root-mean-squared (RMS) difference between measured and predicted groundwater elevations should be at or near a minimum, and 2) All residuals (i.e., the difference between predicted and measured elevations) should be less than one foot. The second of these criteria is quite stringent, given the large area of interest and large number of sampling points in the calibration target.

3.3 OBJECTIVE FUNCTION DEFINITION AND EVALUATION

The root mean squared (RMS) error is commonly used to express the average difference between simulated and measured elevations, and was used as the objective function for the calibration. RMS error is the square root of the average of the squared differences between measured and simulated elevations, and can be expressed as:

$$\mathrm{RMS} = \left[\frac{1}{n} \sum_{i=1}^{n} (h_m - h_s)_i^2 \right]^{0.5}$$

where: n = the number of points where elevations are being compared,
h_m = measured elevation value, and
h_s = simulated elevation value.

A percentage error may be obtained by dividing the RMS error by the total range of measured elevations (maximum measured elevation minus minimum measured elevation). Lower values of the RMS error indicate better fits between modeled and measured elevations, and vice versa. The overall calibration strategy consisted of minimizing the RMS error while attempting to keep all prediction residuals below 1 foot.

To obtain simulated elevation values (h_s in the above equation) at the same locations as measured values (h_m), a post-processing code (CALERR, a Fortran code listed in Appendix B) was written to interpolate simulated results to the correct monitoring well locations. Mean error, RMS error, and RMS percent error were then calculated, and the residuals were contoured.

3.4 PUMPING, RE-INJECTION, AND RESULTS FOR INITIAL RE-CALIBRATION RUN

The starting point for this re-calibration was the previously calibrated Great Miami Aquifer steady-state flow model. As mentioned above, this model was calibrated to June 1993 groundwater elevation data and later converted from SWIFT to VAM3D as part of the groundwater model upgrade project (HydroGeoLogic 1998). The number of model layers was doubled in the conversion from SWIFT to VAM3D, but to demonstrate correspondence between SWIFT and VAM3D, pumping and injection well screen intervals were not refined to the degree made possible by the additional model layers in the VAM3D model. The calibrated model consisted of zoned hydraulic conductivities, specified-head and specified-flux boundary conditions found to be most consistent with the June 1993 groundwater elevation data.

To obtain an initial re-calibration run, the previously calibrated model was modified to reflect current pumping/re-injection conditions, to more accurately represent pumping and injection well screen intervals with the increased number of model layers, and to incorporate revised estimates of specified-flux boundary conditions. The "VAMAB1" run from the VAM3D conversion report (HydroGeoLogic 1998) was chosen as the basis from which to implement the necessary changes. The "VAMAB1" run simulates steady-state flow with 1400 gpm pumping at the South Plume Pumping System (Figure 2, Wells RW1 through RW4). The following changes were made to "VAMAB1" to obtain initial results under current conditions:

- Increased net surface infiltration from 6 inches/year to 50 inches/year in the Southeast Drainage Ditch. This ditch runs north across Willey Road onto the site and joins the SSOD. Recharge from this ditch is indicated by water quality sampling, flow direction measurements using a colloidal borescope, and the location of the uranium plume.

- Added 16 extraction/re-injection wells with a combined pumping rate of 2000 gpm and a combined re-injection rate of 1000 gpm: 9 South Field wells at 1500 gpm total pumping (Figure 2, Wells EW13, EW14, and EW 16 through EW22. Well EW15 had already been turned off by October 1998), 2 South Plume wells at 500 gpm total pumping (Figure 2, Wells RW6 and RW7), and 5 Re-injection Demonstration wells at 1000 gpm total re-injection (Figure 2, Wells IW8 through IW12).

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- Increased the pumping rate at existing South Plume Pumping Well RW4 from 400 gpm to 500 gpm, bringing South Plume total pumping to 1500 gpm, and net pumping to 2500 gpm (3500 gpm pumping minus 1000 gpm re-injection).

- Used pumping/re-injection well construction data to refine well screen intervals on new 12-layer VAM3D grid. See Figure 7.2 of the HydroGeoLogic 1998 reference for a typical comparison of SWIFT 6-layer vertical grid with the VAM3D 12-layer vertical grid. The larger number of layers in the VAM3D grid allows a more faithful representation of actual well screen intervals than the SWIFT model provides.

- Interpolated boundary heads for a 2500 gpm net pumping case from the old SWIFT vertical grid (6 layers) to the new VAM3D vertical grid (12 layers).

- Adjusted SOWC pumping well rates to reflect current pumping conditions: north well (Collector Well #2) changed from 10 mgd to 12 mgd, south (Collector Well #1) changed from 8 mgd to 6 mgd.

The groundwater elevations predicted by the model after the above changes are shown in Figure 3-2, which depicts steady-state groundwater elevations across the second layer of the model. The residuals between simulated and measured heads are contoured in Figure 3-3. The objective function was evaluated for the initial simulation and the RMS error was 1.08 feet and RMS percent error was 10.1 percent. These relatively low errors indicated that the previously calibrated model did not need a great deal of improvement even though it didn't meet the calibration criteria. The subsequent calibration procedure consisted of incrementally changing initial model conditions until the calibration criteria were met.

3.5 CALIBRATION SIMULATIONS

Changes to model parameters during the course of calibration fell into three categories:

1) Changes to specified-head conditions at the lateral boundaries of the model and at the Great Miami River top surface boundary.

2) Changes to hydraulic conductivity.

3) Changes to specified-flux (net recharge) conditions at the top surface of the model.

Examination of initial residuals in Figure 4 indicated that the calibration could be improved significantly by changing specified-head boundary conditions. A Fortran program was developed to use the contoured residuals to adjust specified boundary and river heads (See Appendix B). Using this procedure, the RMS prediction error was quickly reduced to 0.6 feet or 5.6 percent.

After this initial calibration run, two problem areas were addressed to further improve the calibration:

- In the Paddys Run area, predicted elevations were generally low with several residuals lower than -1 foot. In particular, predictions were low at a localized, seasonal groundwater mound beneath Paddys Run near the waste pit area. Several approaches were tried to simulate the formation of this groundwater mound, but none were effective. These approaches included combinations of the following: 1) extending a high-recharge zone (176.5 in/yr) in Paddys Run north by 9 grid elements; 2) increasing rates in the high-recharge zone from 176.5 in/yr to 224 in/yr (a 27 percent increase); and, 3) lowering Upper Great Miami Aquifer conductivities (from 638 and 270 ft/d to 120 ft/d horizontal, from 51 and 21.6 ft/d to 9.6 ft/d vertical) along Paddys Run in the mound vicinity. The model displayed little sensitivity to any of these changes. Only change 1 was retained in subsequent runs because observations of the stream bed in this area show that Paddys Run is in direct contact with the sand and gravel of the Great Miami Aquifer.

- The low predicted water elevations at the confluence of the Paddys Run Outlet and the New Haven Trough were corrected by raising model boundary heads by 1.5 feet at the Paddys Run outlet to the Great Miami River. This change brought water elevation predictions at nearly every well within the maximum one-foot residual calibration criterion. Several more minor adjustments were made to the specified-head boundaries to obtain a simulation with a minimum RMS error and residuals less than one foot at each monitoring well. Appendix C , Table C-1, contains tabulated run descriptions and error statistics for each calibration simulation.

Final calibrated groundwater elevations for the second model layer are presented in Figure 3-4. Final RMS and RMS percent errors were 0.33 feet and 3.1 percent, respectively. A contour plot of the residual distribution after calibration is presented in Figure 3-5. A complete listing of calculated and observed elevations for each monitoring well in the calibration target set is included in Table 1 of Appendix A.

3.6 DISCUSSION OF CALIBRATION RESULTS

The calibration process lowered RMS errors from 1.09 feet (10.2 percent) at the start to 0.33 feet (3.1 percent). The maximum one-foot residual criterion was met – the largest negative and positive residuals were -0.73 and 0.82 feet at wells 2065 and 2702, respectively (see Table 1, Appendix A). Despite the low calibration residuals, a pattern of slightly low predictions can still be seen at the location of the groundwater mound near Paddys Run (see Figure 3-5 at coordinates (4000,10000)). The steady-state model fails to reproduce this feature with reasonable changes in recharge or conductivity because the feature is transient in nature, and due to localized effects. This has been previously confirmed from groundwater elevation data and contoured water table maps. This mounding feature results from a fast buildup due to extremely high recharge in Paddys Run during storm events. The presence of limited-extent impermeable zones in the Upper Great Miami Aquifer may exacerbate or prolong the effects of such transients.

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As mentioned in the introduction, one motivation for recalibrating the flow model was to improve the agreement between modeled and measured flow directions in the vicinity of the southeast corner of the site. The discrepancy can be seen by examining Figures 3-1 and 3-2. Figure 3-2 is the initial head distribution obtained with the previously calibrated model, and shows a southwesterly flow direction at the 517-foot contour near the site southeast corner. Figure 3-1 on the other hand, depicts measured elevations and indicates flow nearly straight south in the same zone, with a more radial flow pattern further east as the 517-foot contour swings around to the north along the site eastern boundary. Examination of the final recalibrated head distribution in Figure 3-4 shows that the newly calibrated model produces a much more accurate representation of flow directions in this region.

Among the changes made to model parameters during the calibration process, the following were retained as a permanent part of the newly calibrated model:

- Specified-head boundaries were adjusted at all lateral boundaries and at surface Great Miami River nodes. Specified heads were generally increased at west and southwest boundaries, and decreased at north, east, southeast, and Great Miami River boundaries.
- The high-recharge (176.5 in/yr) zone at the north end of Paddys Run was extended north by 9 grid elements (1125 ft).

These changes were generated during the iterative calibration process, and are in addition to the changes detailed in Section 3.4.

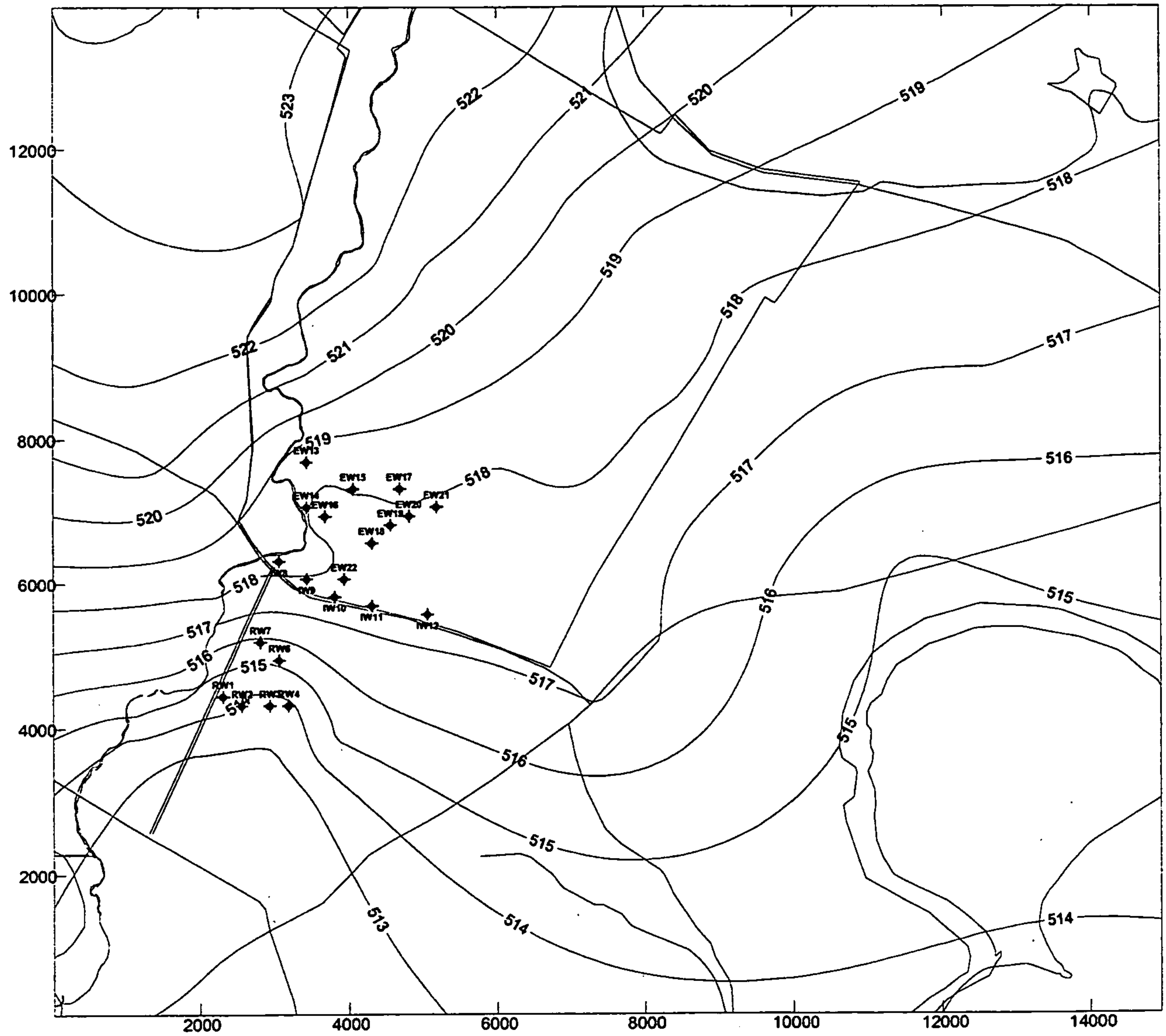

FIGURE 3-1 CALIBRATION TARGET – CONTOURED WATER ELEVATION DATA FROM OCTOBER, 1998.

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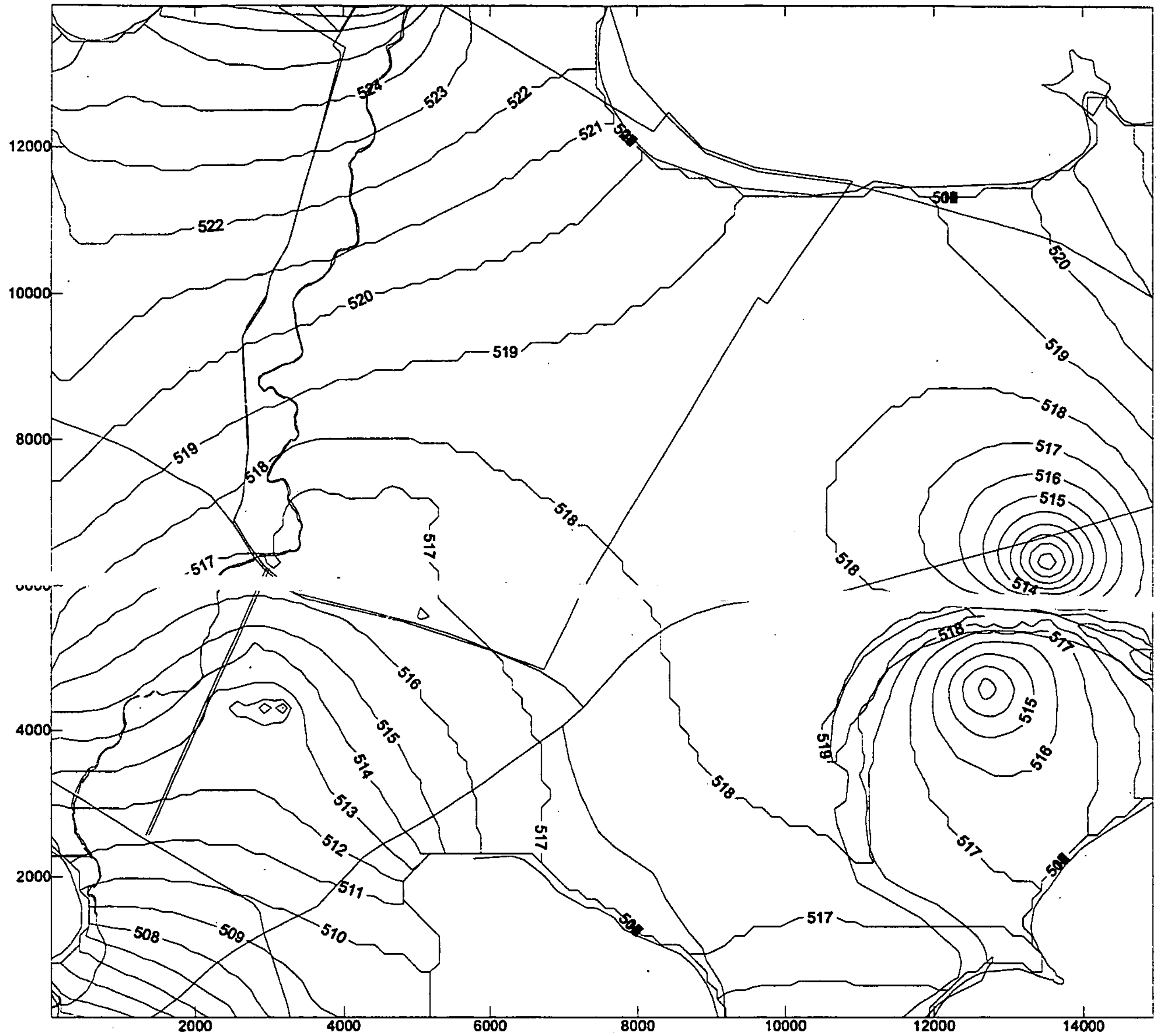

FIGURE 3-2 SIMULATED WATER TABLE AT START OF CALIBRATION PROCEDURE.

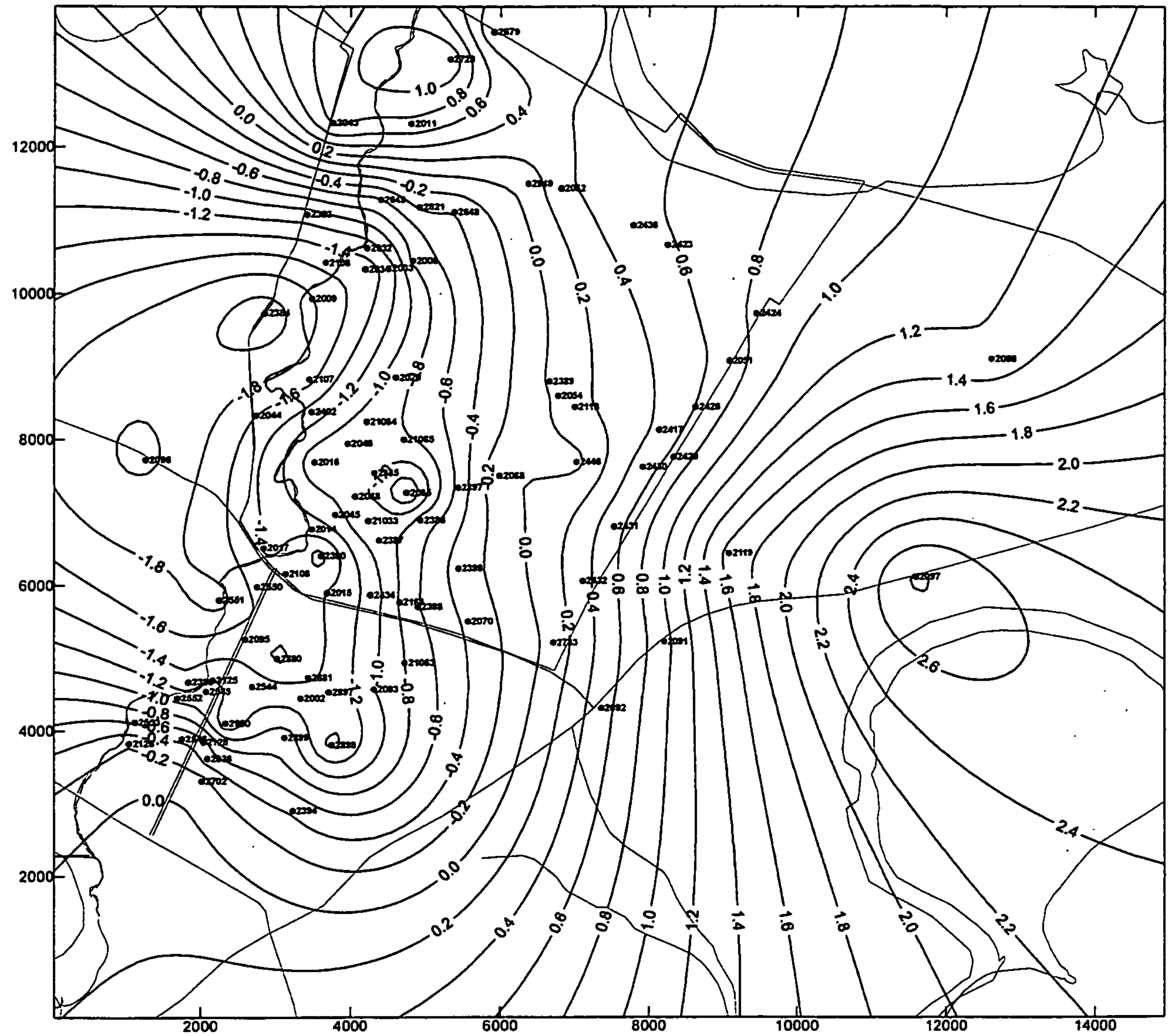

FIGURE 3-3 RESIDUALS BETWEEN SIMULATED AND MEASURED WATER ELEVATIONS AT START OF CALIBRATION PROCEDURE

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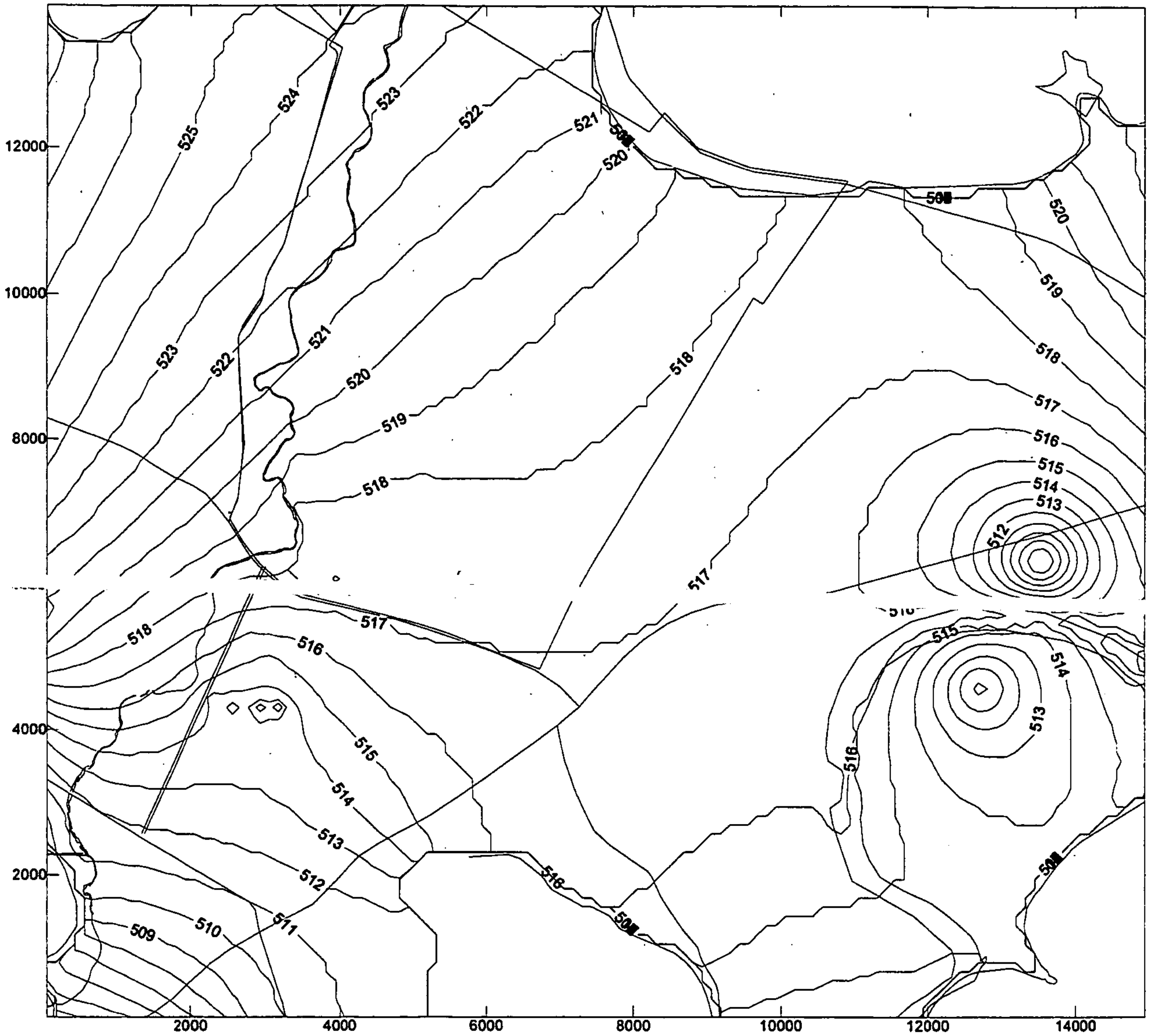

FIGURE 3-4 SIMULATED WATER TABLE AT END OF CALIBRATION PROCEDURE.

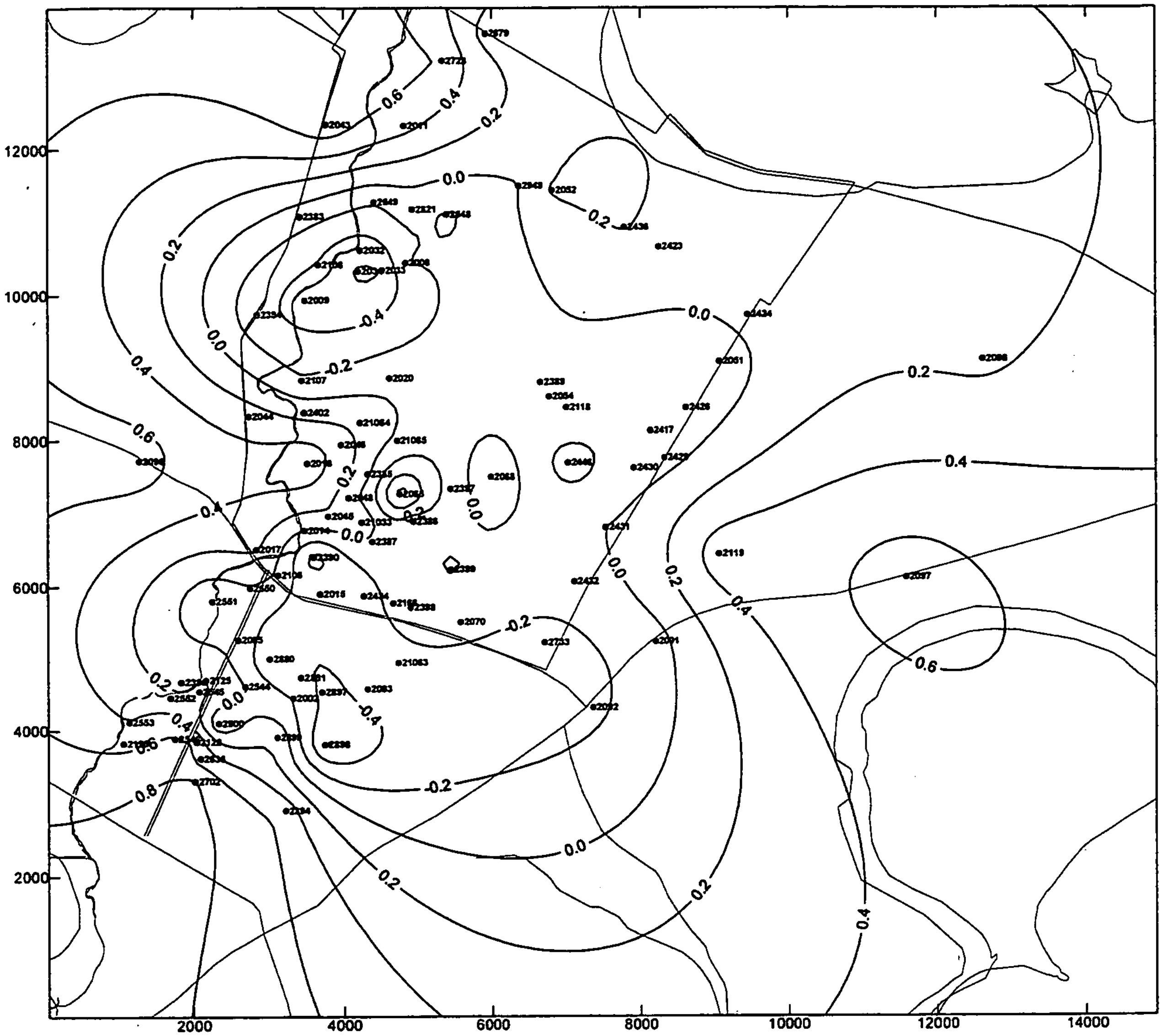

FIGURE 3-5 RESIDUALS BETWEEN SIMULATED AND MEASURED WATER ELEVATIONS AT END OF CALIBRATION PROCEDURE.

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4.0 STEADY-STATE FLOW MODEL VALIDATION

4.1 VALIDATION TARGET

To select a validation target, available groundwater elevation data were surveyed to determine the most complete set from a period of extreme groundwater elevations and pumping/re-injection conditions different from the two previous calibration periods (June 1993 and October 1998). It was determined that the April 1998 water level data set best fit the requirements. Use of this data set was appropriate as it was obtained during one of the wettest months in recent history (9.37 inches of precipitation in April 1998), and from a wetter-than-normal year. Great Miami Aquifer water elevations during April 1998 were at or near the highest levels recorded in recent history. It was assumed that the recalibrated model would be quite robust if it was reasonably accurate at reproducing April 1998 water elevations. Figure 4-1 is a contour plot of the April 1998 validation target. The validation data set is included in Table 2 of Appendix A.

4.2 VALIDATION CRITERIA

Ideally, validation predictions would meet the same criteria as the calibration. However, because the validation target data reflect extreme aquifer conditions, it was recognized that residuals and RMS errors were likely to be significantly higher than for calibration. Examination of rainfall data revealed that a two-day, 3.95-inch rainfall event preceded groundwater elevation data collection by three days (rainfall on April 15-16, 1998 and data collection on April 20-21, 1998). While this helped create extreme conditions under which to test the model, it probably induced transient effects in the aquifer which are impossible to reproduce with a realistic steady-state flow model. Given these factors, the validation strategy was simply to assess an initial RMS error and then reduce the error as much as possible while using physically plausible model parameters and boundary conditions. It is assumed that final RMS errors for the April 1998 validation data set represent an upper bound on errors expected when applying the calibrated model.

4.3 OBJECTIVE FUNCTION DEFINITION AND EVALUATION

As in the calibration, the RMS error was used as the objective function. Incremental changes were made to boundary condition parameters until significant reductions in RMS error were no longer observed.

4.4 PUMPING, RE-INJECTION, AND RESULTS FOR INITIAL VALIDATION RUN

The April 1998 validation period preceded startup of the South Field, South Plume, and Re-injection Demonstration Systems. To obtain the appropriate aquifer stress conditions for validation, wells representing these systems were removed from the calibrated model input file. This resulted in 2000 gpm less pumping and 1000 gpm less re-injection than for the calibrated case.

Once the pumping/re-injection conditions in the calibrated model were changed to match validation conditions, the first simulation was run and the objective function was evaluated. The initial RMS error was 2.68 feet and RMS percent error was 28.2 percent. This error is over eight times as large as the 0.33-foot final calibration error. Much of this relatively large initial error was attributed to the use of specified heads and fluxes from the calibrated model, which are compatible with the lower water table of the October 1998 period.

4.5 VALIDATION SIMULATIONS

Because calibrated boundary conditions appeared to cause a large RMS error for the first validation run, initial validation iterations focused on adjusting boundary fluxes and heads to obtain a lower RMS error. The following three steps (performed in succession) were found to reduce the RMS error to a level below which significant improvement could not be made:

1) Increase by a factor of four all surface recharge rates in the model except for the 6 inch/year background rate assigned to model zones with glacial till cover.

2) Add 2.5 feet to specified heads along the Paddys Run outlet to the Great Miami River and along the west model boundary between 0 and 11000 feet. Also, add to existing specified heads along the west boundary amounts varying linearly from 2.5 feet at 11000 feet to zero at the northwest corner (13937.5 ft).

3) Subtract 0.3 feet from all boundary heads except at the Great Miami River, which was left unchanged.

The RMS error after these three steps was reduced to 1.26 ft (13.3 percent). Parameter changes were made to try improving the agreement between predicted and measured elevations. These included local and global changes in hydraulic conductivity, local and global changes in specified recharge rates, and further adjustments of boundary heads (see Appendix C, Table C-2). None of the changes was found to significantly improve the RMS error, although a couple of changes produced slight decreases (as low as 12.4 percent error). Changes that produced lower errors included a 50 percent increase in Upper Great Miami Aquifer hydraulic conductivities and local large reductions of east and north boundary heads. Given the accurate calibration obtained previously and the generally high water levels for the validation period, these changes were not considered physically plausible. Some of the global changes in conductivity and recharge were formalized into a brief sensitivity analysis, detailed in the following section.

Final validated heads and head residuals are presented in Figures 4-2 and 4-3. Final RMS and RMS percent errors were 1.26 feet and 13.3 percent, respectively. A complete listing of predicted and observed elevations for each monitoring well in the validation target set is included in Table 2 of Appendix A.

4.6 SENSITIVITY ANALYSIS

To demonstrate the sensitivity of the validated model to global changes in hydraulic conductivity and recharge rates, a brief sensitivity analysis was compiled from some of the iterative parameter changes made during the validation process. Table 1 summarizes the results of the sensitivity analysis.

TABLE 4-1

SUMMARY OF SENSITIVITY ANALYSIS RESULTS FOR VALIDATION SIMULATIONS

Description	RMS Error (ft)	RMS Percent Error
Final Validation	1.26	13.3
Multiply All Upper Great Miami Aquifer Conductivities by 1.5	1.18	12.4
Divide All Upper Great Miami Aquifer Conductivities by 1.5	1.40	14.7
Multiply All Recharge Rates by 1.5	1.56	16.4
Low Recharge Rates, Same as Calibrated Model	1.66	17.5
Multiply All Recharge Rates by 1.5, Except 6 in/yr Background	1.45	15.2
Divide All Recharge Rates by 1.5, Except 6 in/yr Background	1.35	14.2

As Table 1 shows, large changes in conductivity and recharge rate have relatively minor effects on the RMS error. Only a 50 percent global increase in hydraulic conductivity resulted in a lower RMS error; however, the decrease was not significant and 50 percent higher conductivities are not considered likely in light of available pumping test data and the excellent calibration results.

4.7 DISCUSSION OF VALIDATION RESULTS

The validation process lowered RMS errors from 2.68 feet (28.2 percent) at the start to 1.26 feet (13.3 percent). The largest negative and positive residuals were -3.56 and 2.35 feet at wells 2097 and 2386, respectively (see Table 2, Appendix A). The large negative residuals at wells 2097 and 2098 (closest to the eastern model boundary) indicate that east-side boundary and Great Miami River heads are probably higher than the final validated values. Indeed, these heads were not significantly changed from the calibrated case even though the high validation water levels would seem to warrant an increase. Such an increase was not possible as it was found to significantly degrade the fit between modeled and measured heads. This was attributed to the lack of monitoring locations near the east boundary and, as explained below, an unusual groundwater trough that formed along the site eastern boundary (see Figure 4-1).

The trough can be seen at Wells 2430, 2429, 2417, 2426, 2051, and 2424 along the site eastern boundary. This feature has not been seen in any other data set and was attributed to lingering transient effects due to the heavy rainfall three days prior to water elevation measurement. It appears that water converging on this zone from the west and east had yet to equilibrate, leaving a linear, shallow depression that paralleled the site eastern boundary. This implies that the data were taken when the aquifer was under transient conditions and therefore the data may not be appropriate for a steady state flow model calibration/validation.

The effect of this trough was to produce a local zone of high model predictions and relatively large positive residuals. These residuals were made worse when east boundary or river heads were raised, even though such changes improved the fit closer to the model boundary.

Other localized zones of high negative and positive residuals (lows centered about Wells 2899 and 2009, and a high at Well 2386) were attributed to similar transient effects. As the above sensitivity analysis indicates, it was not possible to significantly improve the model fit through changes in conductivity or recharge. It was concluded that local zones of irreducible prediction error were due to deviation of measured elevations from a true steady-state condition.

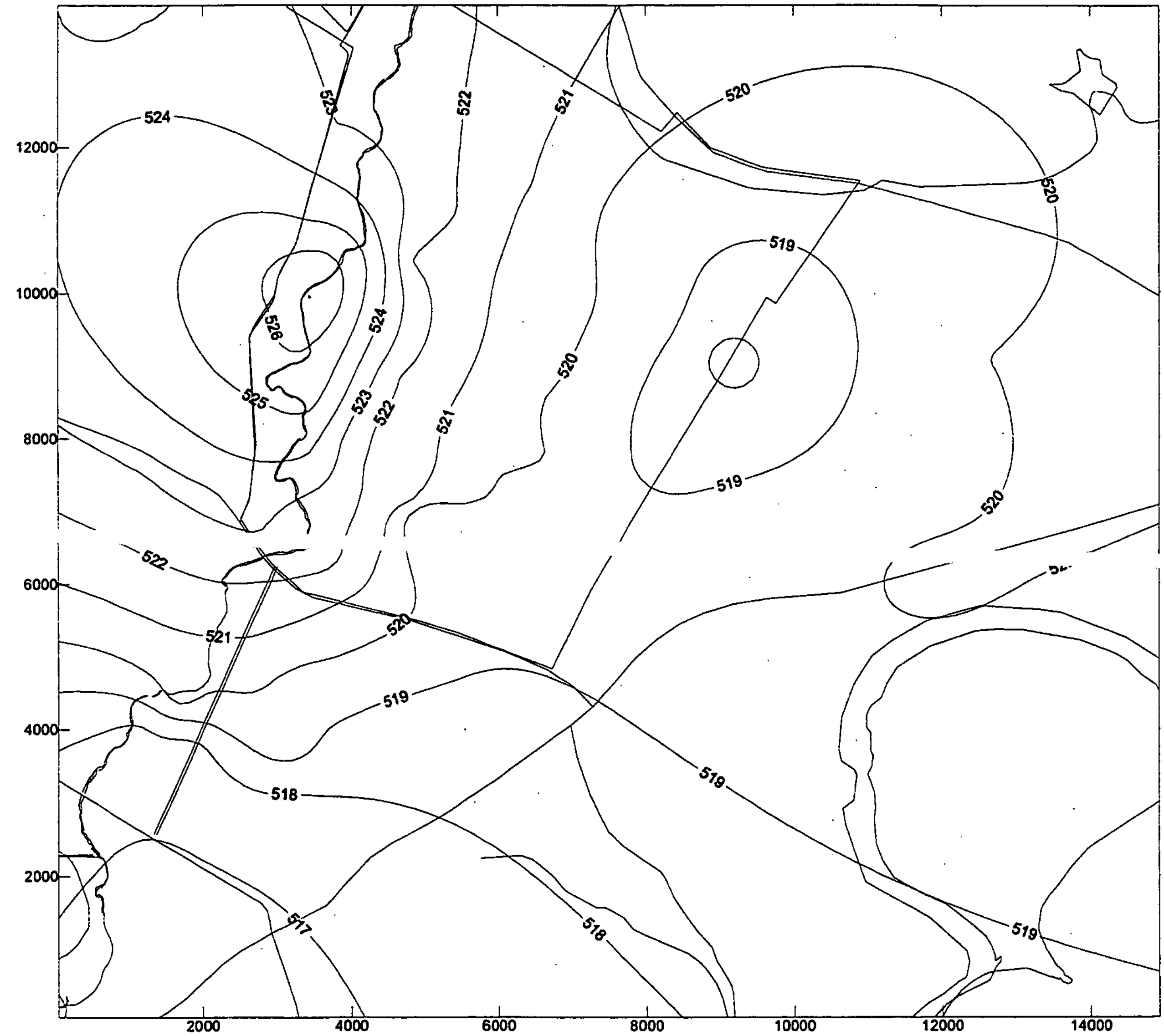

FIGURE 4-1 VALIDATION TARGET – CONTOURED WATER ELEVATION DATA FROM APRIL, 1998.

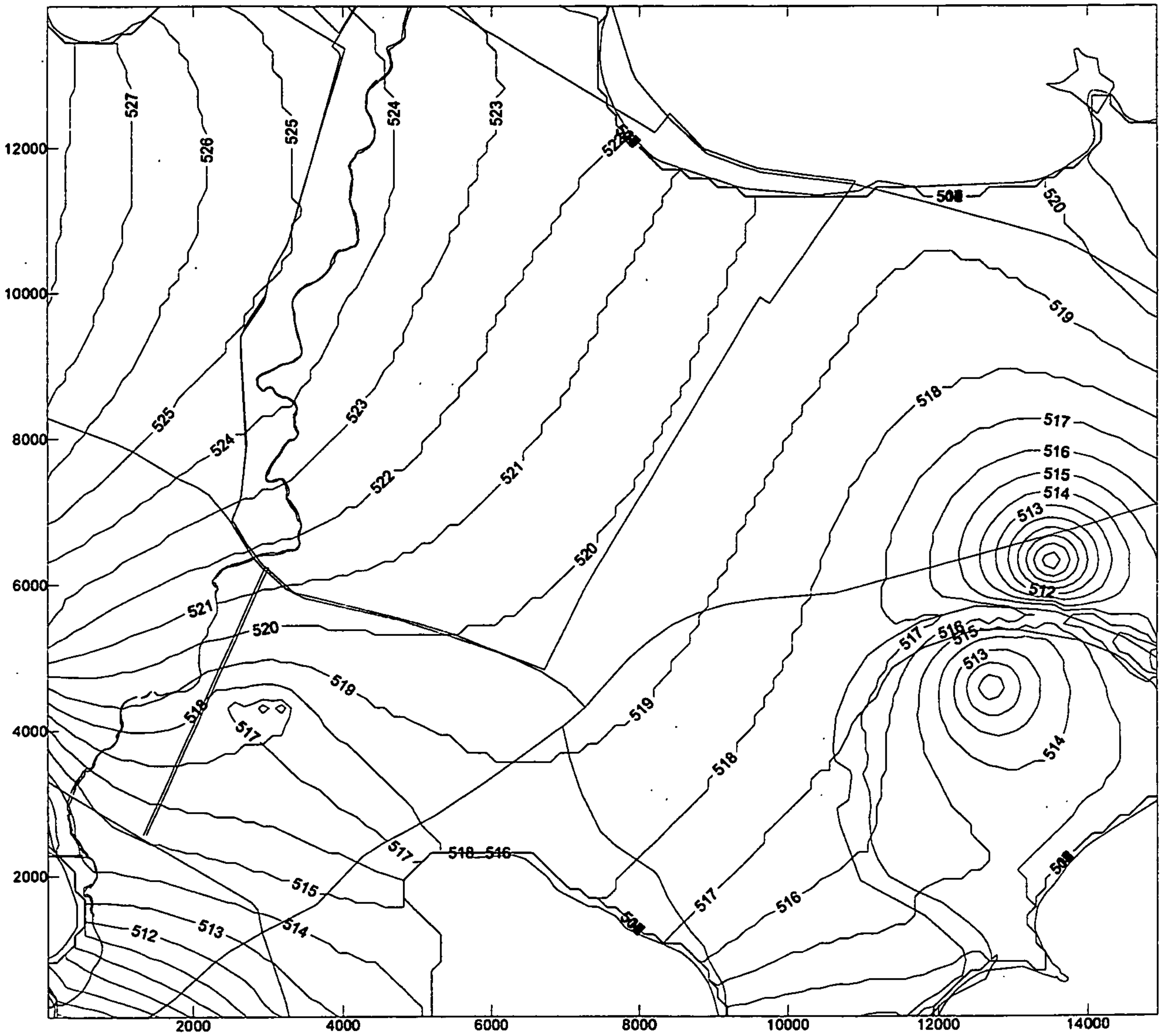

FIGURE 4-2 SIMULATED WATER TABLE AT END OF VALIDATION PROCEDURE.

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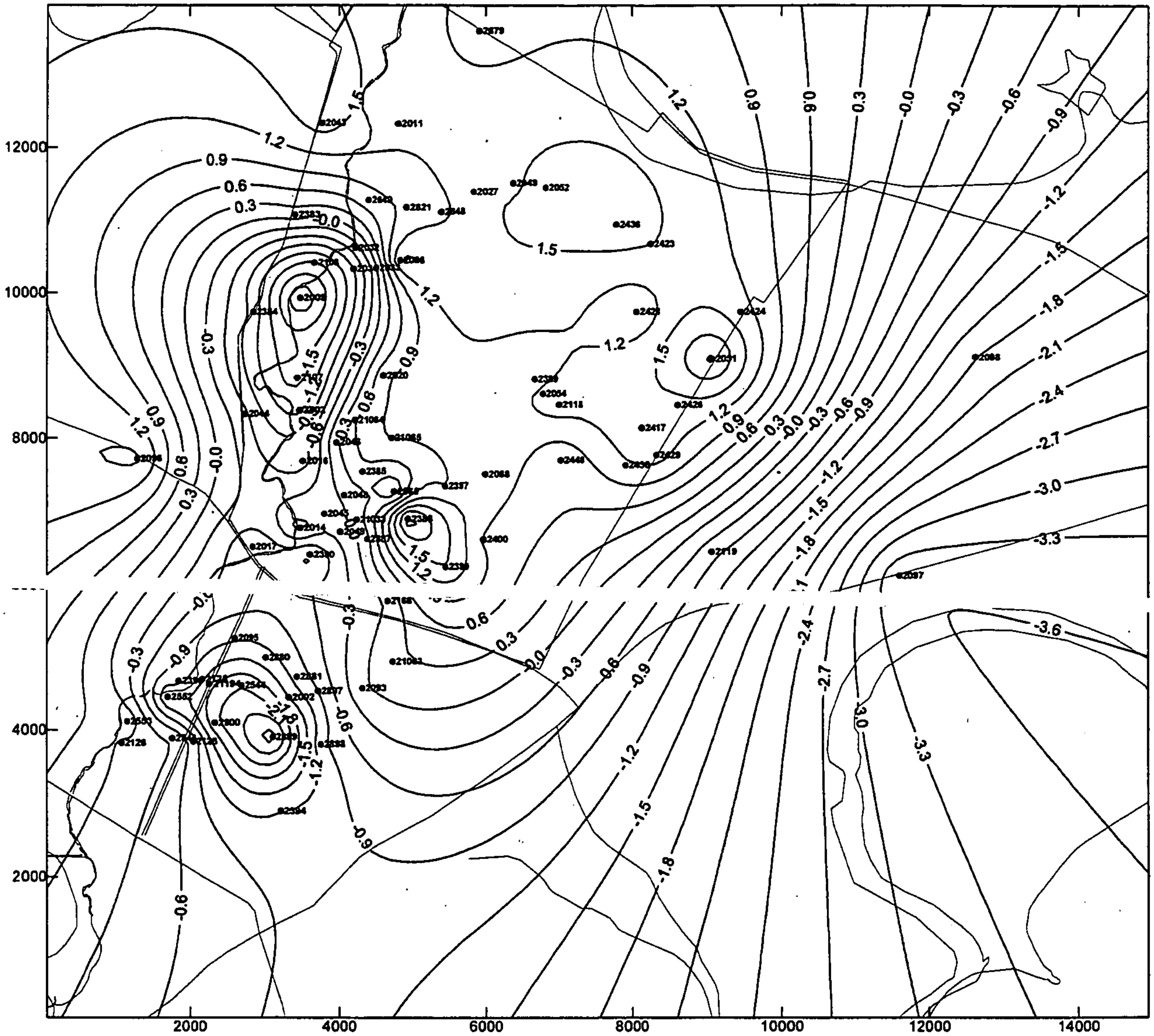

FIGURE 4-3 RESIDUALS BETWEEN SIMULATED AND MEASURED WATER ELEVATIONS AT END OF VALIDATION PROCEDURE.

5.0 SUMMARY AND DISCUSSION

Excellent results were obtained from the steady-state flow re-calibration. As compared to measured October 1998 water elevations, a very low RMS error of 0.33 feet (3.1 percent) was achieved. The calibration incorporates all aquifer stresses which were in affect for the time period being modeled, provides much better agreement between predicted and measured flow directions at the site southeast corner, takes advantage of the vertically refined VAM3D grid, and provides an accurate steady flow solution for future DFM activities. The moderate water elevations of the October 1998 calibration data and excellent calibration results suggest that the recalibrated model will serve well for steady-state simulation of long-term average Great Miami Aquifer conditions.

The validation quantified the maximum RMS error that can be expected when applying the calibrated model to future periods of high Great Miami Aquifer water levels. Despite evidence of significant transient phenomena in the validation data set, a reasonably low RMS error of 1.26 feet (13.3 percent) was still obtained. The April 1998 water elevation data used for validation represents historically high Great Miami Aquifer water elevations and data collection followed by three days a significant 4-inch, 2-day rainfall event. Because of these unusual conditions, it is expected that RMS errors below 1.26 feet will be readily achievable for future wet-condition simulations by setting appropriate boundary conditions in the model as defined by this calibration/validation effort.

In the future, predictions made with the steady-state flow model may involve choice among normal, wet, or dry boundary conditions based upon which conditions best match the most recent water elevation data. In this context, the re-calibrated model would represent normal conditions and the validated model simulates wet conditions. Given the evidence of significant transient effects in the April 1998 validation data set, it appeared advisable to perform a second wet-season validation with a data set that more nearly represents a steady-state condition. It also appeared advisable to perform a dry-condition validation with data from a period of very low aquifer water elevations. These additional validation exercises were performed and documented in Appendix D.

The data selected for the additional wet-condition validation were from quarterly sampling in July, 1998. The dry-condition validation used quarterly sampling data from October, 1999. Both of these additional validations produced excellent results – RMS and RMS percent errors of 0.55 feet and 5.4 percent for the high-water condition, and 0.42 feet and 4.1 percent for the low-water condition. Each of these validated models will be useful to provide bounding estimates under extreme aquifer conditions for future predictions of uranium transport. The additional validations have also shown that the model hydraulic conductivity distribution from the October 1998 recalibration is robust enough to accommodate widely varying aquifer water levels and stress conditions with little loss of accuracy.

6.0 BIBLIOGRAPHY

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APPENDIX A

FINAL CALIBRATION AND VALIDATION RESULTS – LISTING OF OBSERVED HEADS, CALCULATED HEADS, RESIDUALS, AND ERROR STATISTICS AT EACH WELL.

TABLE A-1

10/98 CALIBRATION RESULTS

HEADS IN FEET ABOVE MSL

ID	OBS	CALC	RESID	% ERROR
2002	514.20	513.99	-0.21	-1.9
2008	521.20	521.00	-0.20	-1.9
2009	522.20	521.72	-0.48	-4.5
2011	522.20	522.66	0.46	4.3
2014	518.00	517.99	-0.01	-0.1
2015	517.70	517.40	-0.30	-2.8
2016	518.20	518.75	0.55	5.2
2017	518.40	518.62	0.22	2.1
2020	519.80	519.75	-0.05	-0.5
2032	522.30	521.78	-0.52	-4.9
2033	521.80	521.19	-0.61	-5.7
2034	522.10	521.48	-0.62	-5.8
[illegible]	522.70	523.44	0.74	6.9
2044	520.60	520.90	0.30	2.8
2045	517.60	517.77	0.17	1.6
2046	518.80	519.10	0.30	2.8
2048	518.00	518.07	0.07	0.6
2051	517.90	517.81	-0.09	-0.8
2052	520.20	520.42	0.22	2.1
2054	518.60	518.53	-0.07	-0.6
2065	518.40	517.67	-0.73	-6.8
2068	517.90	518.05	0.15	1.4
2070	517.30	517.15	-0.15	-1.4
2091	517.00	516.92	-0.08	-0.8
2092	517.00	516.76	-0.24	-2.2
2093	516.20	515.89	-0.31	-2.9
2095	516.10	516.06	-0.04	-0.4
2096	521.40	522.10	0.70	6.5
2097	514.80	515.50	0.70	6.5
2098	517.10	517.26	0.16	1.5
21033	517.50	517.66	0.16	1.5
2106	518.10	518.08	-0.02	-0.2
21063	516.80	516.54	-0.26	-2.4
21064	519.20	519.34	0.14	1.3
21065	518.80	518.77	-0.03	-0.3
2107	520.90	520.72	-0.18	-1.7
2108	522.50	522.09	-0.41	-3.9
2118	518.40	518.38	-0.02	-0.2
2119	516.50	517.01	0.51	4.7
2125	515.00	515.20	0.20	1.9
2126	513.90	514.45	0.55	5.1
2128	513.30	513.87	0.57	5.4
2166	517.40	517.26	-0.14	-1.3
2383	523.00	522.90	-0.10	-1.0
2384	522.50	522.16	-0.34	-3.2
2385	518.30	518.35	0.05	0.5

TABLE A-1

(Continued)

2386	517.50	517.41	-0.09	-0.8
2387	517.40	517.37	-0.03	-0.3
2389	518.70	518.68	-0.02	-0.2
2390	518.30	517.81	-0.49	-4.6
2394	512.40	512.92	0.52	4.9
2396	515.70	515.77	0.07	0.7
2397	518.00	517.87	-0.13	-1.2
2398	517.40	517.31	-0.09	-0.8
2399	517.40	517.41	0.01	0.1
2402	520.00	520.13	0.13	1.2
2417	518.00	517.84	-0.16	-1.5
2417	517.90	517.84	-0.06	-0.5
2423	518.70	518.82	0.12	1.2
2424	517.80	517.85	0.05	0.5
2426	517.90	517.77	-0.13	-1.2
2429	517.70	517.63	-0.07	-0.6
2430	517.80	517.72	-0.08	-0.8
2431	517.50	517.50	0.00	0.0
2432	517.40	517.30	-0.10	-0.9
2434	517.60	517.30	-0.30	-2.8
2436	519.10	519.31	0.21	1.9
2446	518.30	518.00	-0.30	-2.8
2544	514.20	514.21	0.01	0.1
2545	514.70	514.98	0.28	2.7
2546	513.60	514.23	0.63	5.9
2550	517.80	517.79	-0.01	-0.1
2551	518.00	517.80	-0.20	-1.9
2552	515.30	515.60	0.30	2.8
2553	514.90	515.30	0.40	3.7
2636	513.00	513.52	0.52	4.8
2648	521.40	521.17	-0.23	-2.2
2649	522.40	522.21	-0.19	-1.8
2679	522.60	522.72	0.12	1.1
2702	512.30	513.12	0.82	7.6
2728	522.30	522.89	0.59	5.5
2733	517.30	517.03	-0.27	-2.6
2821	521.70	521.61	-0.09	-0.8
2880	515.30	514.90	-0.40	-3.8
2881	515.30	514.93	-0.37	-3.4
2897	515.50	515.07	-0.43	-4.0
2898	514.90	514.27	-0.63	-5.9
2899	513.20	513.37	0.17	1.6
2900	513.90	513.72	-0.18	-1.7
2949	520.80	520.79	-0.01	-0.1

AVG RESID = 0.01 FEET
RMS ERROR = 0.33 FEET
RMS % ERROR = 3.12

000033

TABLE A-2

4/98 VALIDATION RESULTS

HEADS IN FEET ABOVE MSL

ID	OBS	CALC	RESID	% ERROR
2002	519.20	517.72	-1.48	-15.6
2008	521.90	523.47	1.57	16.6
2009	527.10	524.70	-2.40	-25.2
2011	522.60	523.88	1.28	13.5
2014	521.90	522.09	0.19	2.0
2015	521.30	520.74	-0.56	-5.9
2016	523.80	523.05	-0.75	-7.9
2017	522.90	522.01	-0.89	-9.3
2020	522.10	522.92	0.82	8.6
2027	521.40	522.89	1.49	15.7
[illegible]	[illegible]	[illegible]	-0.45	-4.7
2033	523.90	523.80	-0.10	-1.1
2034	525.10	524.18	-0.92	-9.7
2043	523.00	524.63	1.63	17.2
2044	524.70	524.17	-0.53	-5.6
2045	522.40	522.12	-0.28	-3.0
2046	522.60	522.89	0.29	3.0
2048	522.10	522.18	0.08	0.9
2049	521.90	521.72	-0.18	-1.9
2051	517.60	519.78	2.18	23.0
2052	520.60	522.22	1.62	17.1
2054	519.80	521.13	1.33	14.0
2065	521.80	521.78	-0.02	-0.2
2068	520.00	521.14	1.14	12.0
2093	519.20	519.15	-0.05	-0.5
2095	521.00	519.85	-1.15	-12.1
2096	523.20	524.77	1.57	16.5
2097	520.10	516.54	-3.56	-37.5
2098	520.00	518.21	-1.79	-18.8
21033	521.60	521.76	0.16	1.7
21063	519.40	519.64	0.24	2.5
21064	522.30	522.90	0.60	6.3
21065	521.40	522.32	0.92	9.7
2107	525.70	524.07	-1.63	-17.1
2108	526.30	524.75	-1.55	-16.3
2118	519.60	520.92	1.32	13.9
2119	519.90	519.10	-0.80	-8.4
21194	520.10	518.39	-1.71	-18.0
2125	520.20	518.76	-1.44	-15.1
2126	517.60	517.53	-0.07	-0.7
2128	518.10	517.41	-0.69	-7.2
2166	520.40	520.43	0.03	0.3
2383	524.80	524.96	0.16	1.7
2384	525.90	524.92	-0.98	-10.3
2385	521.70	522.28	0.58	6.1
2386	519.00	521.35	2.35	24.8

TABLE A-2

(Continued)

2387	521.20	521.40	0.20	2.1
2389	520.30	521.28	0.98	10.3
2390	522.50	521.51	-0.99	-10.4
2394	517.60	516.40	-1.20	-12.6
2396	520.20	519.14	-1.06	-11.1
2397	520.50	521.38	0.88	9.3
2399	519.10	520.62	1.52	16.0
2400	519.80	520.65	0.85	9.0
2402	525.00	523.71	-1.29	-13.6
2417	518.70	520.09	1.39	14.7
2421	519.70	520.62	0.92	9.7
2423	519.30	520.81	1.51	15.9
2424	518.40	519.71	1.31	13.8
2426	518.50	519.88	1.38	14.5
2429	518.50	519.85	1.35	14.2
2430	518.90	520.06	1.16	12.2
2436	519.60	521.28	1.68	17.7
2446	520.00	520.62	0.62	6.5
2544	520.10	518.02	-2.08	-21.9
2546	518.00	517.67	-0.33	-3.5
2550	521.90	521.19	-0.71	-7.5
2552	520.50	518.93	-1.57	-16.6
2553	518.10	518.38	0.28	2.9
2648	522.10	523.18	1.08	11.3
2649	523.50	524.27	0.77	8.1
2679	521.90	522.98	1.08	11.4
2821	522.70	523.65	0.95	10.0
2880	520.40	519.08	-1.32	-13.9
2881	519.70	518.63	-1.07	-11.3
2897	519.50	518.60	-0.90	-9.5
2898	518.70	517.70	-1.00	-10.5
2899	519.90	517.00	-2.90	-30.5
2900	519.40	517.37	-2.03	-21.4
2949	521.10	522.55	1.45	15.3

AVG RESID = 0.01 FEET
RMS ERROR = 1.26 FEET
RMS % ERROR = 13.30

APPENDIX B

LISTING OF AUXILIARY COMPUTER CODES USED DURING CALIBRATION/VALIDATION PROCESS.

```
      program mkvambc
c
c     program to convert 120 X 112 X 6 SWIFT model specified-head
boundary
c     conditions to the 120 X 112 X 12 VAM3D model.  A pre-existing
VAM3D
c     specified-head BC file is assumed, which contains nodes at which
BCs
c     will be specified.  A new VAM3D BC file (group15b.bin) is created
by
c     interpolating SWIFT heads vertically at the appropriate nodes.
c
      implicit real*8(a-h,o-z)
      parameter(nx=120,ny=112,nzs=6,nzv=12,mb=nx*ny*nzs,mbv=nx*ny*nzv)
      dimension p(nx,ny,nzs),zs(nx,ny,nzs),uhb(mb),zv(mbv)
      dimension ish(mbv)
      character*12 version
      rhog=62.37d0/144.d0        ! ft/PSI
c
c     read SWIFT pressures from r1-20.bin
c
      open(unit=8,file='bh3.bin',form='unformatted',status='old')
      read(8)version
      do i=1,nx
       do j=1,ny
        do k=1,nzs
         p(i,j,k)=-1.d30
        end do
       end do
      end do
      do l = 1, 10000000
       read(8,end=100)i1,i2,j1,j2,k1,k2,kaq
       read(8,end=100)x1,x2,x3,x4,x5,x6
       do i=i1,i2
        do j=j1,j2
         do k=k1,k2
          p(i,j,k)=x2
         end do
        end do
       end do
      end do
100   continue
      close(8)
c
c     read SWIFT z-coords from r1-21.bin
c
      open(unit=8,file='c:\swiftmod\r1_21.bin',form='unformatted',
     *            status='old')
      read(8)version
      read(8)iconst
      read(8)(hkx,m=1,mb)
```

```
      read(8)iconst
      read(8)(hky,m=1,mb)
      read(8)iconst
      read(8)(hkz,m=1,mb)
      read(8)iconst
      read(8)phi
      read(8)iconst
      read(8)(uhb(m),m=1,mb)
      read(8)iconst
      read(8)(uthb,m=1,mb)
      read(8)iconst
      read(8)ucpr
      close(8)
      m=0
      do k=1,nzs
       do j=1,ny
        do i=1,nx
         m=m+1
         zs(i,j,k)=1000.d0-uhb(m)
        end do
       end do
      end do
c
c     read VAM3D z-coords from group14b.bin
c
      OPEN(UNIT=8,FILE='C:\VAMMOD\BINDATA\FLOW\GROUP14.BIN',
     *            FORM='UNFORMATTED',status='old')
      READ(8)(XCVR,I=1,nx*ny)
      READ(8)(YCVR,I=1,nx*ny)
      READ(8)(ZV(I),I=1,mbv)
      CLOSE(8)
c
c     read existing VAM3D specified head (group15b) file to get blocks
c     for specification
c
      open(unit=7,file='C:\VAMMOD\BINDATA\FLOW\GROUP15B.BIN',
     *            form='unformatted',status='old')
      do i=1,mbv
       ish(i)=0
      end do
      do i=1,mbv
       read(7,end=101)nd,jd,cdum
       ish(nd)=1
      end do
101   close(7)
c
c     interpolate/WRITE VAM3D boun heads using SWIFT pressures
c
      open(unit=7,file='GROUP15B.BIN',form='unformatted',
     *            status='unknown')
      n=0
```

000038

```
do k=1,nzv
 klo=int(k/2)     ! SWIFT Z-INDEX BRACKETS
 khi=klo+1
 do j=1,ny
  do i=1,nx
   n=n+1
   if(ish(n).gt.0)then
    if(k.eq.1)then
     if(p(i,j,1).lt.-1.d29)then
      write(*,'(a,3i5)')'no spec pres @ SWIFT block ',i,j,1
      stop
     else
      sh=zs(i,j,1)+p(i,j,1)/rhog
     end if
    else if(k.eq.nzv)then
     if(p(i,j,nzs).lt.-1.d29)then
      write(*,'(a,3i5)')'no spec pres @ SWIFT block ',i,j,nzs
      stop
     else
      sh=zs(i,j,nzs)+p(i,j,nzs)/rhog
     end if
    else
     if(p(i,j,klo).lt.-1.d29)then
      write(*,'(a,3i5)')'no spec pres @ SWIFT block ',i,j,klo
      stop
     else if(p(i,j,khi).lt.-1.d29)then
      write(*,'(a,3i5)')'no spec pres @ SWIFT block ',i,j,khi
      stop
     else
      hlo=zs(i,j,klo)+p(i,j,klo)/rhog
      hhi=zs(i,j,khi)+p(i,j,khi)/rhog
      sh=hlo+(hhi-hlo)*(zv(n)-zs(i,j,klo))/
*                        (zs(i,j,khi)-zs(i,j,klo))
     end if
    end if
    write(7)n,1,sh
   end if
  end do
 end do
end do
CLOSE(7)
stop
end
```

```
      PROGRAM WELLSCRN
C
C     PROGRAM TO PLACE WELLS IN PROPER VAM3D LAYERS BASED ON
SWIFT-STYLE
C     ALLOCATION FACTOR WEIGHTING.  THIS CODE ALLOWS FOR
BLOCK-BY-BLOCK
C     VARIATION OF CONDUCTIVITY BY READING IN THE FILES 'GROUP8.BIN'
AND
C     'GROUP9.BIN,' CONTAINING VAM3D NODE NUMBERS AND HYDRAULIC
PROPERTIES.
C
      IMPLICIT REAL*8(A-H,O-Z)

PARAMETER(NX=120,NY=112,NZM=12,NZMP=NZM+1,NWM=200,NNM=NX*NY*NZM)
      DIMENSION WAF(NZM),HK(NZM),HKX(NNM),ZN(NNM),Z(NZMP),MAT(NNM)
      CHARACTER I8*80,I9*80,I14*80,OWF*80,WID*10,IWF*80
C
C
C    READ GROUP 8 INPUT FILE
C
      WRITE(*,*)'ENTER NAME OF GROUP8 (NODE-MAT#) BINARY FILE'
      READ(*,'(A)')I8
      OPEN(8,FILE=I8,STATUS='OLD',FORM='UNFORMATTED')
      READ(8)(MAT(I),I=1,NNM)
      CLOSE(8)
      NAC=0
      DO I=1,NNM
       IF(MAT(I).GT.0)NAC=NAC+1
      END DO
C
C    READ GROUP 9 INPUT FILE
C
      WRITE(*,*)'ENTER NAME OF GROUP9 (MAT#-COND) BINARY FILE'
      READ(*,'(A)')I9
      OPEN(9,FILE=I9,STATUS='OLD',FORM='UNFORMATTED')
      DO I=1,NAC
       READ(9)HKX(I),HKY,HKZ,SW,PHI,ZERO1,ZERO2
      END DO
      CLOSE(9)
C
C    READ GROUP 14 INPUT FILE
C
      WRITE(*,*)'ENTER NAME OF GROUP14 (NODE-Z) BINARY FILE'
      READ(*,'(A)')I14
      OPEN(14,FILE=I14,STATUS='OLD',FORM='UNFORMATTED')
      READ(14)(XCVR,I=1,NX*NY)
      READ(14)(YCVR,I=1,NX*NY)
      READ(14)(ZN(I),I=1,NNM)
      CLOSE(14)
C
      WRITE(*,*)'ENTER NAME OF INPUT WELL FILE'
```

000040

```
      READ(*,'(A)')IWF
      OPEN(11,FILE=IWF,STATUS='OLD')
      WRITE(*,*)'ENTER NAME OF OUTPUT WELL FILE'
      READ(*,'(A)')OWF
      OPEN(12,FILE=OWF,STATUS='UNKNOWN')
C
C
      DO I=1,NWM
       READ(11,'(A10,2I5,3F10.0)',END=100)WID,IW,JW,ZT,ZB,PRT
C
       PRT=PRT*231.D0*60.D0*24.D0/(12.D0**3)   ! GPM -> CU.FT/D
       N=(JW-1)*NX+IW
       Z(1)=ZN(N)
       IF(MAT(N).GT.0)THEN
        HK(1)=HKX(MAT(N))
       ELSE
        HK(1)=0.D0
       END IF
       DO K=2,NZM
        NN=N
        N=N+NX*NY
        Z(K)=(ZN(N)+ZN(NN))/2.D0
        IF(MAT(N).GT.0)THEN
         HK(K)=HKX(MAT(N))
        ELSE
         HK(K)=0.D0
        END IF
       END DO
       Z(NZM+1)=ZN(N)
C
       IF(ZT.GT.ZB.AND.ZT.GT.Z(NZM+1).AND.ZB.LT.Z(1))THEN
        IF(ZT.GT.Z(1))ZT=Z(1)
        IF(ZB.LT.Z(NZM+1))ZB=Z(NZM+1)
        DO K1=1,NZM
         IF(ZT.GT.Z(K1+1))GOTO 80
        END DO
 80     CONTINUE
        DO K2=NZM,1,-1
         IF(ZB.LT.Z(K2))GOTO 90
        END DO
 90     CONTINUE
        IF(K2.GT.K1)THEN
         WAF(K1)=HK(K1)*(ZT-Z(K1+1))
         WAFT=WAF(K1)
         DO K=K1+1,K2-1
          WAF(K)=HK(K)*(Z(K)-Z(K+1))
          WAFT=WAFT+WAF(K)
         END DO
         WAF(K2)=HK(K2)*(Z(K2)-ZB)
         WAFT=WAFT+WAF(K2)
         IF(WAFT.EQ.0.D0)THEN
```

```
              WRITE(*,'(2(A,I3))')'WELL SPECIFIED IN INACTIVE ZONE @ ',
     *                                 IW,',',JW
              GOTO 100
             END IF
             DO K=K1,K2
              WAF(K)=WAF(K)/WAFT
             END DO
            ELSE
             WAF(K1)=1.D0
            END IF
C
C         WRITE OUT GROUP15C CARDS
C
            DO K=K1,K2
             NODE=(K-1)*NX*NY+(JW-1)*NX+IW
             IF(WAF(K).GT.0)WRITE(12,'(2I6,F10.2)')NODE,1,WAF(K)*PRT
            END DO
C
           ELSE
            WRITE(*,'(A,I5)')'SCREEN INTERVAL INPUT ERROR, WELL',I
            WRITE(12,'(A,I5)')'SCREEN INTERVAL INPUT ERROR, WELL',I
            GOTO 100
           END IF
          END DO
100       STOP
          END
```

000042

```
      PROGRAM CALERR
C
C     PROGRAM TO READ CALIBRATION WELL HEAD OBS DATA, READ VAM3D HEAD
OUTPUT,
C     INTERPOLATE CALCULATED HEADS TO OBS LOCATIONS, AND CALCULATE
RESDIUALS
C     AND STATISTICS
C
      IMPLICIT REAL*8(A-H,O-Z)
      REAL*8 TI
      PARAMETER(NP=161280,NEM=145299,NX=120,NY=112,NZ=12,NWM=200)
      DIMENSION X(NP),Y(NP),Z(NP),H(NP),NOP(NEM,8),TPR(20)
      DIMENSION XW(NWM),YW(NWM),ZW(NWM),HW(NWM)
      CHARACTER IFN8*100,TITLE*80,STR1*13,TFN*100,WID(NWM)*10
      PI=4.D0*DATAN(1.D+0)
      XE0=1348479.8D0           ! FT
      YN0=469226.9D0            ! FT
      TH=30.D0*PI/180.D0        ! RADIANS
      STH=DSIN(TH)
      CTH=DCOS(TH)
C
      WRITE(*,*)'ENTER NAME OF CALIBRATION TARGET DATA FILE'
      READ(*,'(A)')TFN
      OPEN(21,FILE=TFN,STATUS='OLD')
      HWMIN=1.D+15
      HWMAX=-1.D+15
      DO I=1,100000
       READ(21,'(A10,4E10.0)',END=98)WID(I),WE,WN,ZW(I),HW(I)
       IF(WID(I).EQ.'          ')GOTO 98
       XW(I)=CTH*(WE-XE0)+STH*(WN-YN0)
       YW(I)=-STH*(WE-XE0)+CTH*(WN-YN0)
       IF(HW(I).GT.HWMAX)HWMAX=HW(I)
       IF(HW(I).LT.HWMIN)HWMIN=HW(I)
      END DO
98    CONTINUE
      NW=I-1
C
      WRITE(*,*)'ENTER VAM3D *.T10 FILE TYPE: 0=ASCII, 1=BINARY'
      READ(*,*)IFT8
      WRITE(*,*)'ENTER *.T10 FILE ROOT NAME INCLUDING PATH'
      READ(*,'(A)')IFN8
      DO I=1,100
       IF(IFN8(I:I).EQ.' '.OR.IFN8(I:I).EQ.'.')GOTO 99
      END DO
99    CONTINUE
      NCH=I-1
C
      NNOD=NX*NY*NZ
      IF(NNOD.LE.NP)THEN
       CONTINUE
      ELSE
```

```
       IF(NNOD.GT.NP)WRITE(*,'(2A)')'PARAMETER NP TOO SMALL OR ',
     *                             'NX*NY*NZ TOO LARGE'
       STOP
      END IF
C
C     OPEN INPUT FILE, READ HEADER AND INITIAL CONDITION
C
      IF(IFT8.EQ.0)THEN
       OPEN(UNIT=8,FILE=IFN8(1:NCH)//'.t10',FORM='FORMATTED',
     *      STATUS='OLD')
       READ(8,*)
       READ(8,*)
       READ(8,*)
       READ(8,'(3I6)')IMODL,NN,NE
C      IF(IMODL.NE.1)THEN
C       WRITE(*,*)' *.T10 IS NOT A FLOW SIMULATION OUTPUT FILE'
C       STOP
C      END IF
       READ(8,*)
       READ(8,'(4(1X,F15.0))')(X(I),Y(I),Z(I),H(I),I=1,NN)
      ELSE
       OPEN(UNIT=8,FILE=IFN8(1:NCH)//'.t10',FORM='UNFORMATTED',
     *      STATUS='OLD')
       READ(8)TITLE,IMODL,NN,NE
C      IF(IMODL.NE.1)THEN
C       WRITE(*,*)' *.T10 IS NOT A FLOW SIMULATION OUTPUT FILE'
C       STOP
C      END IF
       READ(8)(X(I),Y(I),Z(I),I=1,NN)
       READ(8)STR1
       READ(8)(H(I),I=1,NN)
       READ(8)((NOP(I,J),J=1,8),I=1,NE)
      END IF
C
C     OPEN ERROR STATISTIC FILE AND RESIDUAL X,Y,Z FILE
C
      OPEN(UNIT=11,FILE=IFN8(1:NCH)//'.err',STATUS='UNKNOWN')
      OPEN(UNIT=12,FILE=IFN8(1:NCH)//'.res',STATUS='UNKNOWN')
C
      TI=0.D0
      NPR=1
      TPR(NPR)=TI
C
C
      DO WHILE(1.GT.0)
       WRITE(*,*)
       WRITE(*,*)'ENTER TIME (d) FOR WHICH TO COMPUTE ERROR STATS'
       WRITE(*,*)'               < 0, QUIT'
       READ(*,*)TIME
       IF(TIME.LT.0)GOTO 101
C
```

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```
C
        DO WHILE(DABS(TI-TIME).GT.1.D-3)
         IF(IFT8.EQ.0)THEN
          READ(8,'(26X,E10.0)',END=100)TI
          READ(8,'(4(1X,F15.0))',END=100)(X(I),Y(I),Z(I),H(I),I=1,NN)
         ELSE
          READ(8,END=100)IDUM,TI
C         READ(8,END=100)IDUM
C         READ(8,END=100)TI
          READ(8,END=100)(H(I),I=1,NN)
         END IF
         NPR=NPR+1
         TPR(NPR)=TI
         IF(TI.GT.TIME+1.D-3)GOTO 100
        END DO
C
C
        SE=0.D0
        SSE=0.D0
        WRITE(11,*)
        WRITE(11,*)'     HEADS IN FEET ABOVE MSL'
        WRITE(11,*)
        WRITE(11,*)
        WRITE(11,'(5(1X,A9))')'ID       ','      OBS','     CALC',
     *                     '    RESID','  % ERROR'
        WRITE(11,*)
        DO I=1,NW
         CALL INTERP(WID(I),XW(I),YW(I),ZW(I),NX,NY,NZ,X,Y,Z,H,HINT)
         RES=HINT-HW(I)
         SE=SE+RES
         SSE=SSE+RES*RES
         PER=100.D0*RES/(HWMAX-HWMIN)
         WRITE(11,'(A10,3F10.2,F10.1)')WID(I),HW(I),HINT,RES,PER
         WRITE(12,'(3F10.2)')XW(I),YW(I),RES
        END DO
        AVR=SE/NW
        RMS=DSQRT(SSE/NW)
        RMSP=100.D0*RMS/(HWMAX-HWMIN)
        WRITE(11,*)
        WRITE(11,*)
        WRITE(11,'(A,F10.2,A)')'AVG RESID   = ',AVR,' FEET'
        WRITE(11,'(A,F10.2,A)')'RMS ERROR   = ',RMS,' FEET'
        WRITE(11,'(A,F10.2)')'RMS % ERROR = ',RMSP
        WRITE(11,*)
        WRITE(11,*)
C
      END DO
100   CONTINUE
      WRITE(*,*)
      WRITE(*,'(A,F10.3)')'RECORD NOT FOUND AT TIME = ',TIME
101   CONTINUE
```

```
      WRITE(*,*)
      DO I=1,NPR
       WRITE(*,'(A,F10.3)')'     RECORD FOUND AT TIME = ',TPR(I)
      END DO
C
      STOP
      END


      SUBROUTINE INTERP(WID,XW,YW,ZW,NX,NY,NZ,X,Y,Z,H,HINT)
      IMPLICIT REAL*8(A-H,O-Z)
      PARAMETER(NP=161280)
      DIMENSION X(NP),Y(NP),Z(NP),H(NP)
      CHARACTER*10 WID
C
C     X-DIRECTION BRACKET
C
      I=1
      DO WHILE(X(I).LT.XW)
       I=I+1
       IF(I.GT.NX)THEN
        WRITE(*,'(A,A)')'X-COORD TOO HIGH FOR WELL ',WID
        STOP
       END IF
      END DO
      IF(I.EQ.1)THEN
       WRITE(*,'(A,A)')'X-COORD TOO LOW FOR WELL ',WID
       STOP
      END IF
      I1=I-1
      X1=X(I1)
      I2=I
      X2=X(I2)
C
C     Y-DIRECTION BRACKET
C
      J=1
      NN=1
      DO WHILE(Y(NN).LT.YW)
       J=J+1
       NN=(J-1)*NX+1            ! VAM3D NODE #
       IF(J.GT.NY)THEN
        WRITE(*,'(A,A)')'Y-COORD TOO HIGH FOR WELL ',WID
        STOP
       END IF
      END DO
      IF(J.EQ.1)THEN
       WRITE(*,'(A,A)')'Y-COORD TOO LOW FOR WELL ',WID
       STOP
      END IF
```

```
      J1=J-1
      Y1=Y((J1-1)*NX+1)
      J2=J
      Y2=Y((J2-1)*NX+1)
C
C     VERTICAL INTERPOLATION AT FOUR (I,J) CORNERS
C
      CALL ZINT(WID,I1,J1,NX,NY,NZ,ZW,Z,H,H1)
      CALL ZINT(WID,I2,J1,NX,NY,NZ,ZW,Z,H,H2)
      CALL ZINT(WID,I2,J2,NX,NY,NZ,ZW,Z,H,H3)
      CALL ZINT(WID,I1,J2,NX,NY,NZ,ZW,Z,H,H4)
C
C     BILINEAR INTERPOLATION OF CORNER VALUES H1 THRU H4
C
      T=(XW-X1)/(X2-X1)
      U=(YW-Y1)/(Y2-Y1)
      HINT=(1.D0-T)*(1.D0-U)*H1+T*(1.D0-U)*H2+T*U*H3+(1.D0-T)*U*H4
C
      RETURN
      END


      SUBROUTINE ZINT(WID,I,J,NX,NY,NZ,ZW,Z,H,HINT)
      IMPLICIT REAL*8(A-H,O-Z)
      PARAMETER(NP=161280)
      DIMENSION Z(NP),H(NP)
      CHARACTER*10 WID
C
C     Z-DIRECTION BRACKET
C
      K=NZ
      NN=((K-1)*NY+J-1)*NX+I              ! VAM3D I,J,K -> VAM3D NODE #
      DO WHILE(Z(NN).LT.ZW)
       K=K-1
       NN=((K-1)*NY+J-1)*NX+I             ! VAM3D I,J,K -> VAM3D NODE #
       IF(K.LT.1)THEN
        WRITE(*,'(A,A)')'Z-COORD TOO HIGH FOR WELL ',WID
        STOP
       END IF
      END DO
      IF(K.EQ.NZ)THEN
       WRITE(*,'(A,A)')'Z-COORD TOO LOW FOR WELL ',WID
       STOP
      END IF
      K1=K+1
      NN1=((K1-1)*NY+J-1)*NX+I            ! VAM3D I,J,K -> VAM3D NODE #
      K2=K
      NN2=((K2-1)*NY+J-1)*NX+I            ! VAM3D I,J,K -> VAM3D NODE #
C
C      INTERPOLATE H AT (I,J)
```

```
C
      SF=(ZW-Z(NN1))/(Z(NN2)-Z(NN1))
      HINT=H(NN1)+SF*(H(NN2)-H(NN1))
C
      RETURN
      END
```

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```
      PROGRAM BCLINSEG
C
C     PROGRAM TO CHANGE SPEC HEAD BOUNDARY CONDITIONS BY
ADDING/SUBTRACTING
C     PIECEWISE LINEAR HEAD CORRECTION PROFILES ALONG PERIPHERAL
BOUNDARIES.
C     HEADS CONTAINED IN A VAM3D GROUP 15B FILE.
C
      IMPLICIT REAL*8(A-H,O-Z)
      PARAMETER(NNM=161280,NXM=120,NYM=112)
      DIMENSION
CI(NNM),MAT(NNM),RES(NXM,NYM),J1(NYM),CJ1(NYM),J2(NYM),
     *CJ2(NYM),I1(NXM),CI1(NXM),I2(NXM),CI2(NXM),RINT(NXM)
      CHARACTER*100 IFN8,IFN15,OFN
C
      WRITE(*,*)'ENTER GROUP 8 INPUT FILE TYPE: 0=ASCII, 1=BINARY'
      READ(*,*)IFT8
      WRITE(*,'(2A)')'ENTER GROUP 8 INPUT FILE NAME INCLUDING PATH &',
     *               ' EXTENSION'
      READ(*,'(A)')IFN8
C
      WRITE(*,*)'ENTER GROUP 15b INPUT FILE TYPE: 0=ASCII, 1=BINARY'
      READ(*,*)IFT15
      WRITE(*,'(2A)')'ENTER GROUP 15b INPUT FILE NAME INCLUDING PATH
&',
     *               ' EXTENSION'
      READ(*,'(A)')IFN15
C
      WRITE(*,'(2A)')'ENTER BINARY GROUP 15b OUTPUT FILE NAME
INCLUDING'
     *              ,' PATH & EXTENSION'
      READ(*,'(A)')OFN
C
      WRITE(*,*)'ENTER GRID DIMENSIONS: NX,NY,NZ'
      READ(*,*)NX,NY,NZ
C
      NNOD=NX*NY*NZ
      IF(NNOD.LE.NNM)THEN
       CONTINUE
      ELSE
       WRITE(*,'(2A)')'PARAMETER NNM TOO SMALL OR NX*NY*NZ TOO LARGE'
       STOP
      END IF
C
C     READ GROUP 8 INPUT FILE
C
      IF(IFT8.EQ.0)THEN
       OPEN(UNIT=8,FILE=IFN8,FORM='FORMATTED',STATUS='OLD')
       READ(8,'(16I6)')(MAT(I),I=1,NNOD)
       CLOSE(8)
      ELSE
```

```
        OPEN(UNIT=8,FILE=IFN8,FORM='UNFORMATTED',STATUS='OLD')
        READ(8)(MAT(I),I=1,NNOD)
        CLOSE(8)
       END IF
C
       DO I=1,NNOD
        IF(MAT(I).EQ.0)THEN
         CI(I)=-9999.D0           ! INACTIVE NODE (CANNOT BE SPECIFIED
AS BC)
        ELSE
         CI(I)=-999.D0            ! ACTIVE NODE (CAN BE SPECIFIED AS BC)
        END IF
       END DO
C
C      READ GROUP 15b INPUT FILE
C
       IF(IFT15.EQ.0)THEN
        OPEN(UNIT=19,FILE=IFN15,FORM='FORMATTED',STATUS='OLD')
        DO I=1,NNOD
         READ(19,'(2I6,E10.0)',END=91)ND,ID,CI(ND)
        END DO
 91     CLOSE(19)
       ELSE
        OPEN(UNIT=19,FILE=IFN15,FORM='UNFORMATTED',STATUS='OLD')
        DO I=1,NNOD
         READ(19,END=92)ND,ID,CI(ND)
        END DO
 92     CLOSE(19)
       END IF
C
C      READ PIECEWISE LINEAR HEAD CORRECTION DATA
C
       DO I=1,NX
        DO J=1,NY
         RES(I,J)=0.D0
        END DO
       END DO
C
C      CYCLE THROUGH BOUNDARIES CW STARTING AT ORIGIN IN LOWER LEFT
C
C      I=1 BOUNDARY (X=XMIN)
C
       DO L=1,10000               ! J1D ASSUMED IN ASCENDING ORDER
        READ(*,*)J1D,CORD         ! CORD IS CORRECTION IN FEET
        IF(J1D.EQ.0)GOTO 101      ! J1D=0 ENDS INPUT ALONG I=1
        J1(L)=J1D
        CJ1(L)=CORD
       END DO
101    NJ1=L-1
       CALL INTERP(NY,NJ1,J1,CJ1,RINT)
       I=1
```

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```
      DO J=1,NY
       RES(I,J)=RINT(J)
      END DO
C
C     J=NY BOUNDARY (Y=YMAX)
C
      DO L=1,10000                 ! I2D ASSUMED IN ASCENDING ORDER
       READ(*,*)I2D,CORD           ! CORD IS CORRECTION IN FEET
       IF(I2D.EQ.0)GOTO 104        ! I2D=0 ENDS INPUT ALONG I=NX
       I2(L)=I2D
       CI2(L)=CORD
      END DO
104   NI2=L-1
      CALL INTERP(NX,NI2,I2,CI2,RINT)
      J=NY
      DO I=1,NX
       RES(I,J)=RINT(I)
      END DO
C
C     I=NX BOUNDARY (X=XMAX)
C
      DO L=1,10000                 ! J2D ASSUMED IN ASCENDING ORDER
       READ(*,*)J2D,CORD           ! CORD IS CORRECTION IN FEET
       IF(J2D.EQ.0)GOTO 103        ! J2D=0 ENDS INPUT ALONG I=NX
       J2(L)=J2D
       CJ2(L)=CORD
      END DO
103   NJ2=L-1
      CALL INTERP(NY,NJ2,J2,CJ2,RINT)
      I=NX
      DO J=1,NY
       RES(I,J)=RINT(J)
      END DO
C
C     J=1 BOUNDARY (Y=YMIN)
C
      DO L=1,10000                 ! I1D ASSUMED IN ASCENDING ORDER
       READ(*,*)I1D,CORD           ! CORD IS CORRECTION IN FEET
       IF(I1D.EQ.0)GOTO 102        ! I1D=0 ENDS INPUT ALONG J=1
       I1(L)=I1D
       CI1(L)=CORD
      END DO
102   NI1=L-1
      CALL INTERP(NX,NI1,I1,CI1,RINT)
      J=1
      DO I=1,NX
       RES(I,J)=RINT(I)
      END DO
C
C     READ RIVER HEAD CORRECTION
C
```

```
      READ(*,*)RHC
C
C     CHANGE DIRICHLET BOUNDARY CONDITIONS
C
      CALL BCCHG(NX,NY,NZ,RHC,RES,CI)
C
C     WRITE BINARY GROUP 15b OUTPUT FILE
C
      OPEN(UNIT=10,FILE=OFN,FORM='UNFORMATTED')
      NN=0
      DO I=1,NNOD
       IF(CI(I).GT.-900.D0)THEN
        NN=NN+1
        WRITE(10)I,1,CI(I)
       END IF
      END DO
      CLOSE(10)
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)'  NOTE:'
      WRITE(*,*)
      WRITE(*,'(A,I6)')'  NUMBER OF DIRICHLET BC NODES, NBTO = ',NN
      WRITE(*,*)'  CHANGE NBTO IN COL 1-6 OF GROUP 15a ACCORDINGLY'
      WRITE(*,*)
C
      STOP
      END


      SUBROUTINE INTERP(N,NT,IT,CT,RT)
      IMPLICIT REAL*8(A-H,O-Z)
      PARAMETER(NMAX=120)
      DIMENSION IT(N),CT(N),RT(NMAX)
      DO I=1,N
       RT(I)=0.D0
      END DO
      IF(NT.GT.0)THEN
       RT(IT(1))=CT(1)
       IIT=2
       DO I=IT(1)+1,IT(NT)
        DO WHILE(I.GT.IT(IIT))
         IIT=IIT+1
        END DO
        SF=REAL(I-IT(IIT-1))/REAL(IT(IIT)-IT(IIT-1))
        RT(I)=CT(IIT-1)+SF*(CT(IIT)-CT(IIT-1))
       END DO
      END IF
      RETURN
      END
```

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```
      SUBROUTINE BCCHG(NX,NY,NZ,RHC,RES,PAR)
      IMPLICIT REAL*8(A-H,O-Z)
      PARAMETER(NNM=161280)
      DIMENSION RES(NX,NY),PAR(NNM)
C
      DO K=1,NZ
C
       IF(K.EQ.1)THEN
        DO J=2,NY-1         ! DO TOP SURFACE (RIVER) BOUNDARY
         DO I=2,NX-1
          NV1=((K-1)*NY+J-1)*NX+I             ! VAM3D I,J,K -> VAM3D
NODE #
          IF(PAR(NV1).GT.-9.D2)THEN
           PAR(NV1)=PAR(NV1)+RHC
          END IF
         END DO
        END DO
       END IF
C
       DO I=1,NX,NX-1       ! DO I=1,I=NX BOUNDARIES (INCLUDE CORNERS)
        DO J=1,NY
         NV1=((K-1)*NY+J-1)*NX+I             ! VAM3D I,J,K -> VAM3D NODE
#
         IF(PAR(NV1).GT.-1.D3)PAR(NV1)=PAR(NV1)+RES(I,J)
        END DO
       END DO
C
       DO J=1,NY,NY-1       ! DO J=1,J=NY BOUNDARIES (SKIP CORNERS)
        DO I=2,NX-1
         NV1=((K-1)*NY+J-1)*NX+I             ! VAM3D I,J,K -> VAM3D NODE
#
         IF(PAR(NV1).GT.-1.D3)PAR(NV1)=PAR(NV1)+RES(I,J)
        END DO
       END DO
C
      END DO
C
      RETURN
      END
```

APPENDIX C

RUN DESCRIPTIONS AND ERROR STATISTICS FOR CALIBRATION AND VALIDATION SIMULATIONS.

TABLE C-1

RUN DESCRIPTIONS AND ERROR STATISTICS FOR CALIBRATION SIMULATIONS.

Name	Description	Mean Error (ft)	RMS Error (ft)	RMS Percent Error
FLOCAL01	Initial run, well screens match 6-layer SWIFT model well screens	-0.53	1.08	10.05
FLOCAL02	Same as run 01 except well screens refined on VAM3D 12-layer grid	-0.54	1.08	10.13
FLOCAL03	Same as run 02 except SOWC well rates changed from 10 & 8 to 12 & 6 MGD	-0.55	1.08	10.09
FLOCAL04	Same as run 03 except used kriged residuals from run 03 to adjust specified head BCs	-0.28	0.68	6.32
FLOCAL05	Same as run 04 except reduced specified heads at river by 3 feet	-0.92	1.04	9.71
FLOCAL06	Same as run 05 except used kriged residuals from run 05 to adjust specified head BCs	-0.46	0.60	5.64
FLOCAL07	Same as run 06 except increased Paddys Run high recharge rate from 629 to 800 ft/d	-0.45	0.59	5.52
FLOCAL08	Same as run 06 except cleaned up distribution of clay material in layers 7 and 8	-0.46	0.60	5.65
FLOCAL09	Same as run 08 except decreased layer 1 and 2 conductivity beneath Upper Paddys Run mound	-0.47	0.61	5.67
FLOCAL10	Same as run 09 except extended the new low conductivity zone down through layer 4	-0.50	0.64	5.98
FLOCAL11	Same as run 08 except increased all conductivity at south end of Shandon Trough	-0.41	0.57	5.32
FLOCAL12	Same as run 08 except extended Paddys Run high recharge zone north 9 grid blocks	-0.45	0.59	5.49
FLOCAL13	Same as run 12 except raised west boundary heads by 0.5 feet	-0.20	0.43	4.06
FLOCAL14	Same as run 13 except raised boundary heads by 1.5 feet at southwest outlet to Great Miami River	-0.09	0.42	3.92
FLOCAL15	Same as run 12 except made several changes to west and southwest boundary heads	-0.26	0.50	4.72
FLOCAL16	Same as run 14 except changed specified heads at north and west boundaries	-0.10	0.41	3.86
FLOCAL17	Same as run 16 except lowered heads at south part of west boundary	-0.18	0.40	3.74
FLOCAL18	Same as run 17 except raised specified heads by 0.18 feet everywhere	-0.03	0.36	3.40
FLOCAL19	Same as run 18 except enforced hydrostatic condition at east and north boundaries	0.01	0.38	3.58
FLOCAL20	Same as run 19 except subtracted from 0 to 1 foot from west boundary heads	-0.17	0.37	3.49
FLOCAL21	Same as run 20 except raised specified heads by 0.17 feet everywhere	0.01	0.33	3.12

TABLE C-2

RUN DESCRIPTIONS AND ERROR STATISTICS FOR VALIDATION SIMULATIONS.

Name	Description	Mean Error (ft)	RMS Error (ft)	RMS Percent Error
FLOVAL01	Same as calibration run FLOCAL13 except removed S. Field, S. Plume Opt., Reinj. Wells	-2.27	2.77	29.14
FLOVAL02	Same as run 01 except raised specified heads by 2.27 feet everywhere	0.03	1.58	16.59
FLOVAL03	Same as run 02 except used kriged residuals from run 02 to adjust specified head BCs	-0.16	1.63	17.13
FLOVAL04	Same as run 03 except lowered layer 1 and 2 conductivity along Paddys Run	-0.39	1.82	19.13
FLOVAL05	Same as run 04 except doubled all recharge rates where glacial till cover is absent	0.00	1.77	18.68
FLOVAL06	Same as run 04 except quadrupled all recharge rates where glacial till cover is absent	0.64	1.89	19.92
FLOVAL07	Same as run 06 except returned all conductivities to calibrated values	0.77	1.81	19.03
FLOVAL08	Same as run 07 except added a layer 1 & 2 low conductivity corridor along Paddys Run	0.75	1.79	18.85
FLOVAL09	Same as run 07 except added 1.5 feet to boundary heads at southwest outlet to Great Miami River	0.89	1.82	19.17
FLOVAL10	Same as run 09 except subtracted 1.5 feet from east boundary heads north of the Great Miami River	0.75	1.70	17.87
FLOVAL11	Same as run 10 except added from 0 to 1 foot to heads at north end of west boundary	0.84	1.73	18.19
FLOVAL12	Same as run 10 except redid specified head boundaries by tweaking calibrated head BCs	1.60	2.12	22.27
FLOVAL13	Same as run 12 except reduced the tweaks to boundary heads	-0.55	1.77	18.61
FLOVAL14	Same as run 13 except further reduced the tweaks to boundary heads	0.13	1.46	15.37
FLOVAL15	Same as run 14 except added 1.8 feet to west, subtracted 1.8 feet from north boundary heads	0.09	1.32	13.91
FLOVAL16	Same as run 15 except added 1 foot to west, subtracted 2.4 feet from north boundary heads	0.13	1.25	13.21
FLOVAL17	Same as run 16 except added 1/subtracted 6 ft at west/east sides of southern boundary heads	0.10	1.21	12.79
FLOVAL18	Same as run 16 except subtracted from 0 to 1 foot from heads at north end of east boundary	-0.12	1.18	12.45
FLOVAL19	Same as run 16 except redid heads at north and north end of west boundary as per calibration	0.68	1.46	15.41
FLOVAL20	Same as run 19 except subtracted 1 foot from heads at east and southeast boundaries	0.43	1.31	13.78
FLOVAL21	Same as run 20 except redid specified heads by tweaking calibrated boundary heads	-0.05	1.27	13.42
FLOVAL22	Same as run 21 except added 2 feet to heads at west boundary and southwest outlet to Great Miami River	0.01	1.26	13.30

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APPENDIX D

ADDITIONAL MODEL VALIDATIONS FOR HIGH AND LOW WATER ELEVATION CONDITIONS.

D.1 INTRODUCTION

Two additional model validation exercises were performed as recommended in Section 5 (Summary and Discussion). Groundwater elevation data gathered during periods of extreme aquifer conditions were sought for these exercises. The first of these validations used data from quarterly sampling in July, 1998, when Great Miami Aquifer water elevations were very high. The second used quarterly sampling data from October, 1999, when water elevations were very low.

D.2 VALIDATION FOR HIGH AQUIFER WATER ELEVATIONS, JULY 1998

Due to continued heavy rainfall during the early summer of 1998, water levels measured during the July 1998 quarterly sampling were found to be slightly higher than the April 1998 data that comprised the original validation target. Both of these data sets consist of measured water elevations that are higher [illegible] within the last several years. Like the April 1998 set, the July 1998 data set was gathered near the time of a single heavy rainfall. Collection of the April 1998 data followed a 4-inch rainfall by 4 to 6 days, while a 4-inch rainfall (July 19-20) was coincident with the start of July 1998 sampling (July 20-22). From an examination of the July data, it appeared that not enough time had passed between the rainfall event and sampling for obvious transient features to develop. Therefore, compared to the original April 1998 validation, it was anticipated that a better fit between modeled and measured water elevations would be possible for the July 1998 data.

D.2.1 VALIDATION TARGET

As mentioned above, July 1998 water elevation measurements indicate higher water levels than at any time in the last several years. It is anticipated that a model validated with this data will provide useful bounding predictions under the assumption of high water elevations for extended future periods. It was also assumed that good validation results with this data would demonstrate the robustness of the recalibrated model. Figure D.1 is a contour plot of the July 1998 validation target. The validation data set is included in Table D.2.

D.2.2 VALIDATION CRITERIA

The same criteria were used as for the April 1998 validation, described in Section 4.2. However, it was assumed that lower RMS errors would be attainable due to the apparent absence of significant transient water table features.

D.2.3 OBJECTIVE FUNCTION DEFINITION AND EVALUATION

As in the recalibration and initial validation exercises, the RMS error was used as the objective function. Incremental changes were made to boundary condition parameters until significant reductions in RMS error were no longer observed.

D.2.4 AQUIFER PUMPING AND RESULTS FOR INITIAL JULY 1998 VALIDATION RUN

The July 1998 validation data was gathered 8 to 10 days after the startup of the South Field Extraction System. This was a long enough period for transient effects associated with startup to disappear. The input data for the April 1998 validation was used as a starting point for the July 1998 validation. To obtain the appropriate aquifer stress conditions, wells representing the South Field Extraction System were added to the April 1998 validated model input file. This resulted in an added 1500 gpm of pumping at 10 new wells (Wells EW13 through EW22, Figure 2 in the main report). It should be noted that the distribution of pumping among the South Field Extraction wells was slightly different at startup than for the calibration period three months later. At startup, Wells EW15, EW21, and EW22 were pumping at nominal rates of 200, 100, and 200 gpm, respectively; by October 1998 EW15 had been shut down and EW21 and EW22 were increased to 200 and 300 gpm, respectively, to maintain a total South Field Extraction rate of 1500 gpm.

A detailed examination of South Plume Recovery System pumping rates also revealed that Well RW-1 was out of service for much of the July 19-23, 1998 period. Rates at other existing South Plume Recovery Wells (RW-2, RW-3, and RW-4) were increased during at least part of this period in an effort to maintain the total 1500 gpm South Plume pumping. Initial nominal rates (300, 300, 400, and 500 gpm at RW-1, RW-2, RW-3, and RW-4, respectively) were specified for the first validation runs. A later run explored the sensitivity of water elevations in nearby wells to changes in South Plume Recovery Well pumping rates.

The initial July 1998 simulation was based on the April 1998 validation model. Once the pumping conditions in the April 1998 model were changed to match July 1998 conditions, the first simulation was run and the objective function was evaluated. The initial RMS error was 2.27 feet and RMS percent error was 20.9 percent. Much of this initial error was attributed to the use of specified heads from the originally validated model, which reflect a slightly lower water table and the non-steady state conditions of the April 1998 period.

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D.2.5 JULY 1998 VALIDATION SIMULATIONS

Initial validation iterations focused on adjusting boundary heads to obtain a lower RMS error. The following two steps (performed in succession) were found to reduce the RMS error to a level, below which significant improvement could not be made:

1) Increase specified boundary heads by 3 feet at the Great Miami River and the model east and southeast boundaries.

2) Increase all specified boundary and river heads by 1.2 feet.

The RMS error after these two steps was reduced to 0.55 ft (5.4 percent). Residuals between modeled and measured water elevations exceeded 1 foot at only four wells. Of these four wells, one was located at the Paddys Run groundwater mound near the waste pits (Well 2009) and the other three were located near or between the South Plume and South Field Extraction Systems (Wells 21065, 2069, and 2880). No attempt was made to improve the [illegible] Well 2009 because of previous difficulties in improving model predictions at the Paddys Run/waste pits groundwater mound (see Section 3.5 of the main report). Residuals at the three wells near the extraction systems were investigated by examining daily reported extraction system pumping rates over a period (July 19-23, 1998) during which the groundwater elevation measurements were taken. Table D.1 summarizes individual well rates by day over this period and notes the date of measurement at the three monitoring wells.

TABLE D-1

DAILY SUMMARY OF EXTRACTION SYSTEM PUMPING RATES DURING JULY 1998 VALIDATION DATA SAMPLING PERIOD

			July 19, 1998	July 20, 1998	July 21, 1998	July 22 1998	July 23, 1998
Monitoring Wells Sampled					21065, 2880	2069	
Extraction System	**Well #**	**Target Rate (gpm)**	**Pumping Rates (gpm)**				
South Plume	RW-1	300	0	0	94	65	0
	RW-2	300	160	261	398	65	203
	RW-3	400	210	341	520	82	290
	RW-4	500	262	417	657	103	349
South Field	EW-13	200	208	182	228	187	198
	EW-14	200	206	181	226	185	201
	EW-15	200	181	160	196	163	176
	EW-16	200	205	183	224	185	203
	EW-17	100	103	91	109	97	100
	EW-18	100	103	91	115	99	97
	EW-19	100	103	92	114	98	96
	EW-20	100	103	92	114	99	97
	EW-21	100	103	92	115	99	97
	EW-22	200	206	183	227	188	201

The "Target Rate" column in the table lists desired rates for extraction system pumping, which were also the rates specified in model simulations for this period. Table D.1 shows that considerable fluctuation in South Plume pumping occurred during the sampling period, particularly at RW-1 where pumping stopped for much of the period. Moreover, sampling at the three high-residual wells occurred over a two-day period concurrent with the fluctuating pumping. This made it very difficult to determine the effective steady pumping rates "seen" by the monitoring wells. To test the sensitivity of residuals to pumping rates, an additional run was executed with pumping at RW-1 reduced from 300 to 94 gpm. While the overall RMS error was essentially unchanged after this run, localized residuals near RW-1 were changed by as much as 0.5 feet, and were improved by 0.3 feet at Well 2880 (which is 900 feet to the north of RW-1). It was concluded that simultaneous fluctuation in pumping at several surrounding wells could introduce enough uncertainty to account for portions of residuals in excess of 1 foot, and no further simulations were executed.

Final validated heads and head residuals for July 1998 are presented in Figures D.2 and D.3. Final RMS and RMS percent errors were 0.55 feet and 5.4 percent, respectively. For the final validation, a complete listing of predicted and observed elevations at each monitoring well in the validation target set is included in Table D.2. Table D.3 contains a description and summary of error statistics for each of the July 1998 validation runs.

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TABLE D-2

SUMMARY OF OBSERVED AND CALCULATED HEADS, PREDICTION RESIDUALS, AND ERROR STATISTICS, JULY 1998 VALIDATION.

7/98 VALIDATION RESULTS
HEADS IN FEET ABOVE MSL

ID	OBS	CALC	RESID	% ERROR
2002	518.54	518.45	-0.09	-0.9
2008	524.70	524.54	-0.16	-1.6
2009	526.84	525.50	-1.34	-13.2
2011	524.65	525.08	0.43	4.3
2014	521.98	521.71	-0.27	-2.7
2015	521.03	520.87	-0.16	-1.6
2016	522.52	522.57	0.05	0.5
2017	522.51	522.23	-0.28	-2.8
2020	523.46	523.59	0.13	1.3
[illegible]	525.44	524.79	-0.65	-6.5
2034	526.04	525.12	[illegible]	[illegible]
2043	525.06	525.78	0.72	7.1
2044	524.44	524.64	0.20	1.9
2045	521.32	521.49	0.17	1.7
2046	522.75	522.89	0.14	1.4
2048	521.34	521.59	0.25	2.5
2049	521.25	521.40	0.15	1.5
2052	523.22	523.77	0.55	5.4
2054	522.76	522.67	-0.09	-0.9
2065	522.17	521.63	-0.54	-5.4
2068	521.54	522.18	0.64	6.3
2069	519.14	520.84	1.70	16.8
2070	520.94	521.12	0.18	1.8
2091	521.29	521.74	0.45	4.4
2092	521.18	521.43	0.25	2.5
2093	519.88	519.96	0.08	0.7
2095	520.78	520.47	-0.31	-3.0
2097	519.81	520.32	0.51	5.0
2098	522.22	521.91	-0.31	-3.1
21033	521.25	521.43	0.18	1.7
2106	521.42	521.55	0.13	1.2
21063	520.32	520.46	0.14	1.4
21064	522.88	523.18	0.30	2.9
21065	524.46	522.66	-1.80	-17.8
2107	525.44	524.58	-0.86	-8.5
2108	526.45	525.67	-0.78	-7.7
2118	521.97	522.57	0.60	5.9
2119	520.92	521.86	0.94	9.3
21194	519.65	519.17	-0.48	-4.7
2125	519.92	519.55	-0.37	-3.6
2126	518.17	518.55	0.38	3.8
2128	517.54	518.33	0.79	7.8
2166	520.86	520.90	0.04	0.4
22299	522.01	521.78	-0.23	-2.2
22300	521.93	521.29	-0.64	-6.3

TABLE D-2

(Continued)

22301	520.92	520.78	-0.14	-1.4
22303	521.08	520.90	-0.18	-1.8
2383	526.11	525.98	-0.13	-1.2
2384	526.01	525.72	-0.29	-2.9
2385	521.92	522.10	0.18	1.8
2386	521.31	521.41	0.10	1.0
2387	521.09	521.16	0.07	0.7
2389	522.67	522.77	0.10	1.0
2390	521.97	521.41	-0.56	-5.6
2394	516.71	517.41	0.70	6.9
2396	519.97	519.98	0.01	0.1
2397	521.86	521.96	0.10	1.0
2398	520.83	520.95	0.12	1.2
2399	521.02	521.38	0.36	3.5
2400	521.33	521.71	0.38	3.7
2402	524.72	524.00	-0.72	-7.1
2423	522.17	522.92	0.75	7.4
2429	521.69	522.17	0.48	4.7
2434	520.97	520.84	-0.13	-1.3
2436	522.32	523.18	0.86	8.5
2446	522.04	522.28	0.24	2.3
2544	518.66	518.76	0.10	1.0
2545	519.43	519.34	-0.09	-0.9
2546	517.76	518.60	0.84	8.3
2550	521.81	521.60	-0.21	-2.1
2551	522.08	521.74	-0.34	-3.3
2552	519.57	519.81	0.24	2.3
2553	519.26	519.37	0.11	1.1
2648	524.41	524.42	0.01	0.1
2649	526.18	525.38	-0.80	-7.9
2679	523.91	524.22	0.31	3.0
2733	521.25	521.42	0.17	1.7
2821	524.89	524.81	-0.08	-0.8
2880	521.59	519.70	-1.89	-18.6
2881	519.55	519.29	-0.26	-2.5
2897	519.50	519.32	-0.18	-1.8
2898	518.58	518.62	0.04	0.4
2899	518.04	517.86	-0.18	-1.7
2900	518.50	518.23	-0.27	-2.7
2949	523.67	523.99	0.32	3.1

AVG RESID = 0.00 FEET
RMS ERROR = 0.55 FEET
RMS % ERROR = 5.40

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TABLE D-3

RUN DESCRIPTIONS AND ERROR STATISTICS FOR JULY 1998 VALIDATION SIMULATIONS

Name	Description	Mean Error (ft)	RMS Error (ft)	RMS Percent Error
FL2VAL01	Initial run, same as 4/98 validation except South Field Extraction added	-2.14	2.27	20.91
FL2VAL02	Same as run 01 except added 3 feet to east/southeast boundary and river heads	-1.28	1.45	13.38
FL2VAL03 (validated)	Same as run 02 except added 1.2 feet to all boundary and river heads	0.00	0.55	5.40
FL2VAL04	Same as run 03 except decreased South Plume pumping Well RW-1 from 300 to 94 gpm	0.14	0.56	5.56
FL2VAL05	Same as run 04 except subtracted 0.14 feet from all boundary and river heads	0.00	0.55	5.39

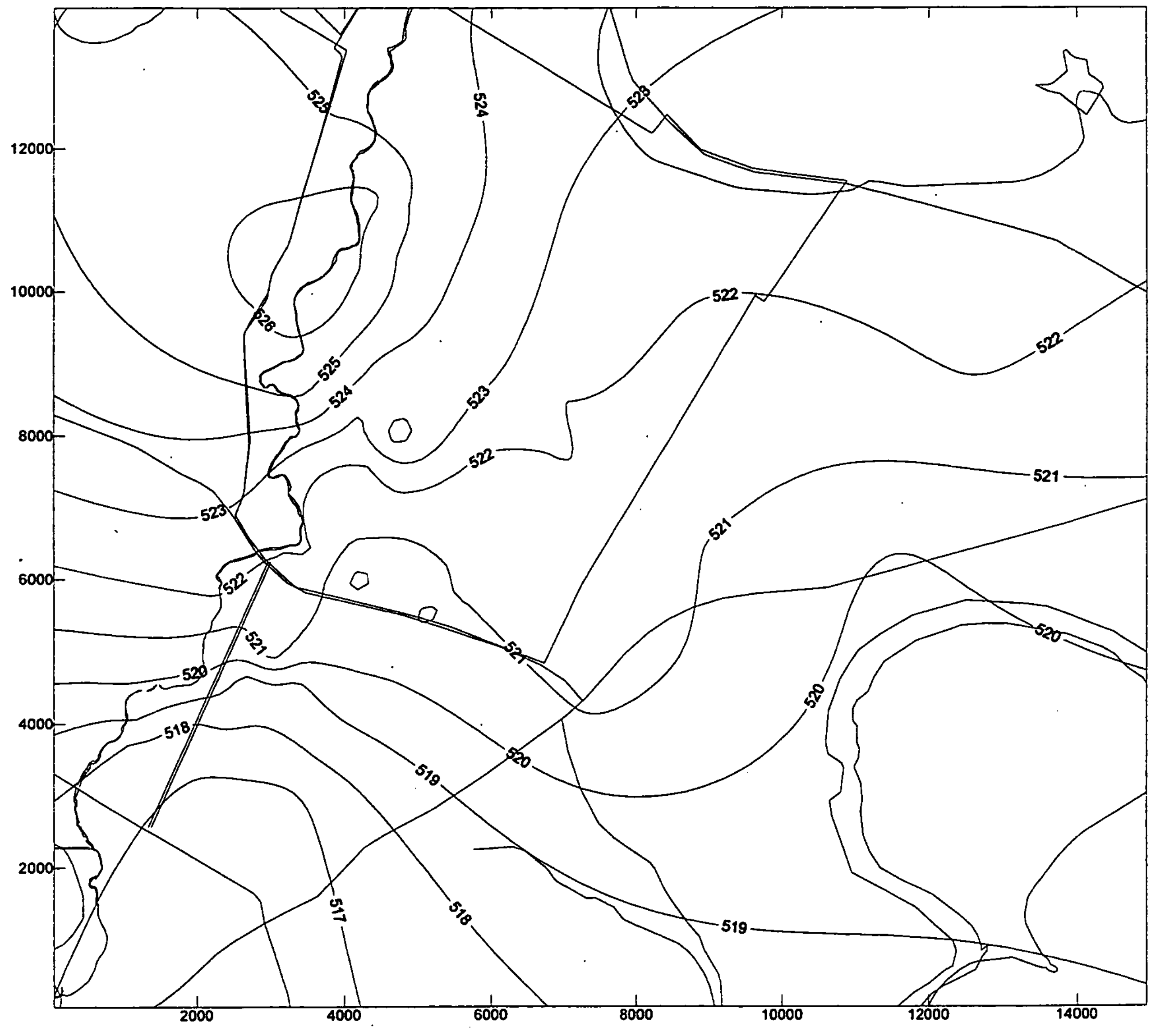

FIGURE D-1 VALIDATION TARGET – CONTOURED WATER ELEVATION DATA FROM JULY, 1998.

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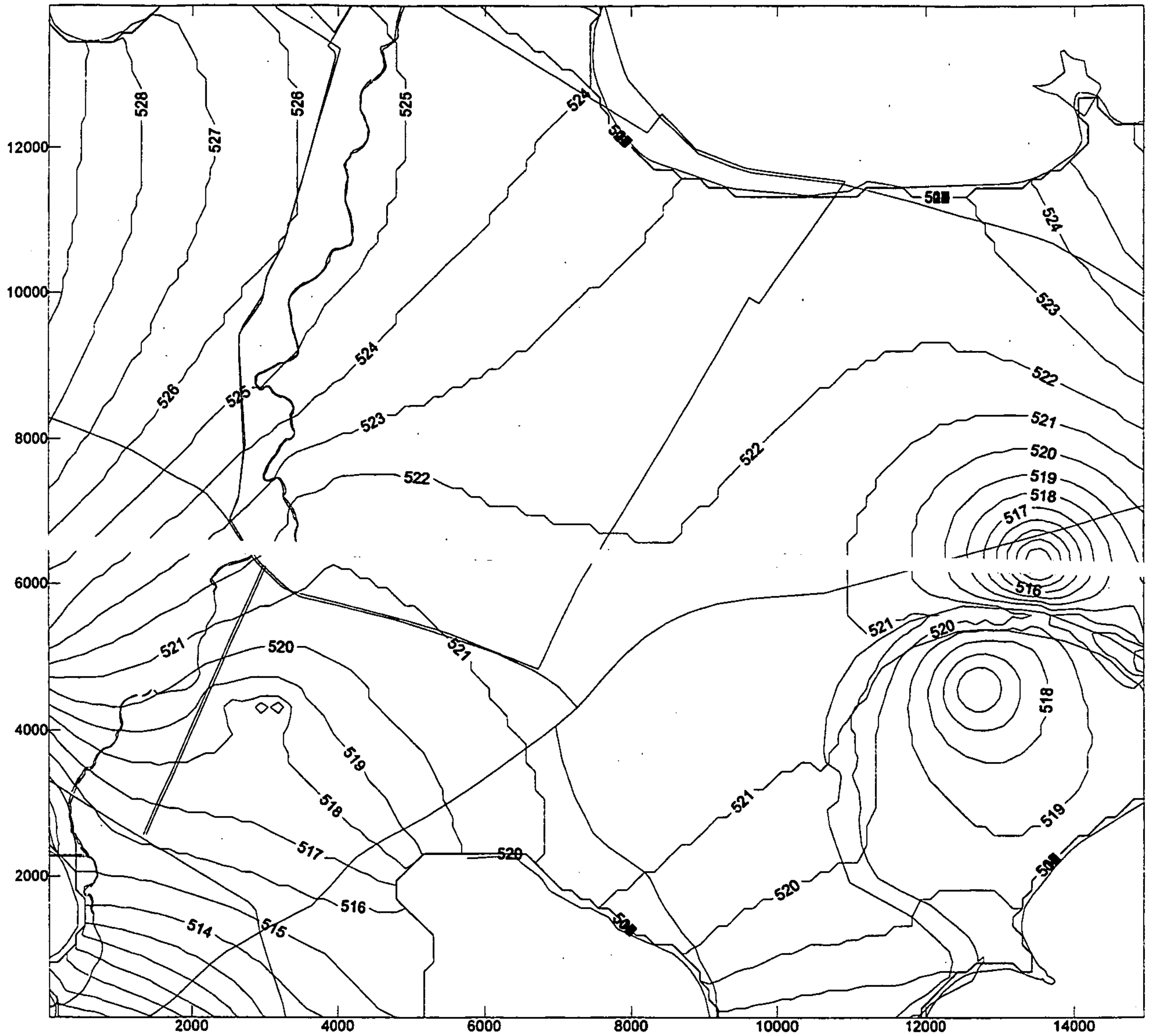

FIGURE D-2 SIMULATED WATER TABLE AT END OF JULY 1998 VALIDATION PROCEDURE.

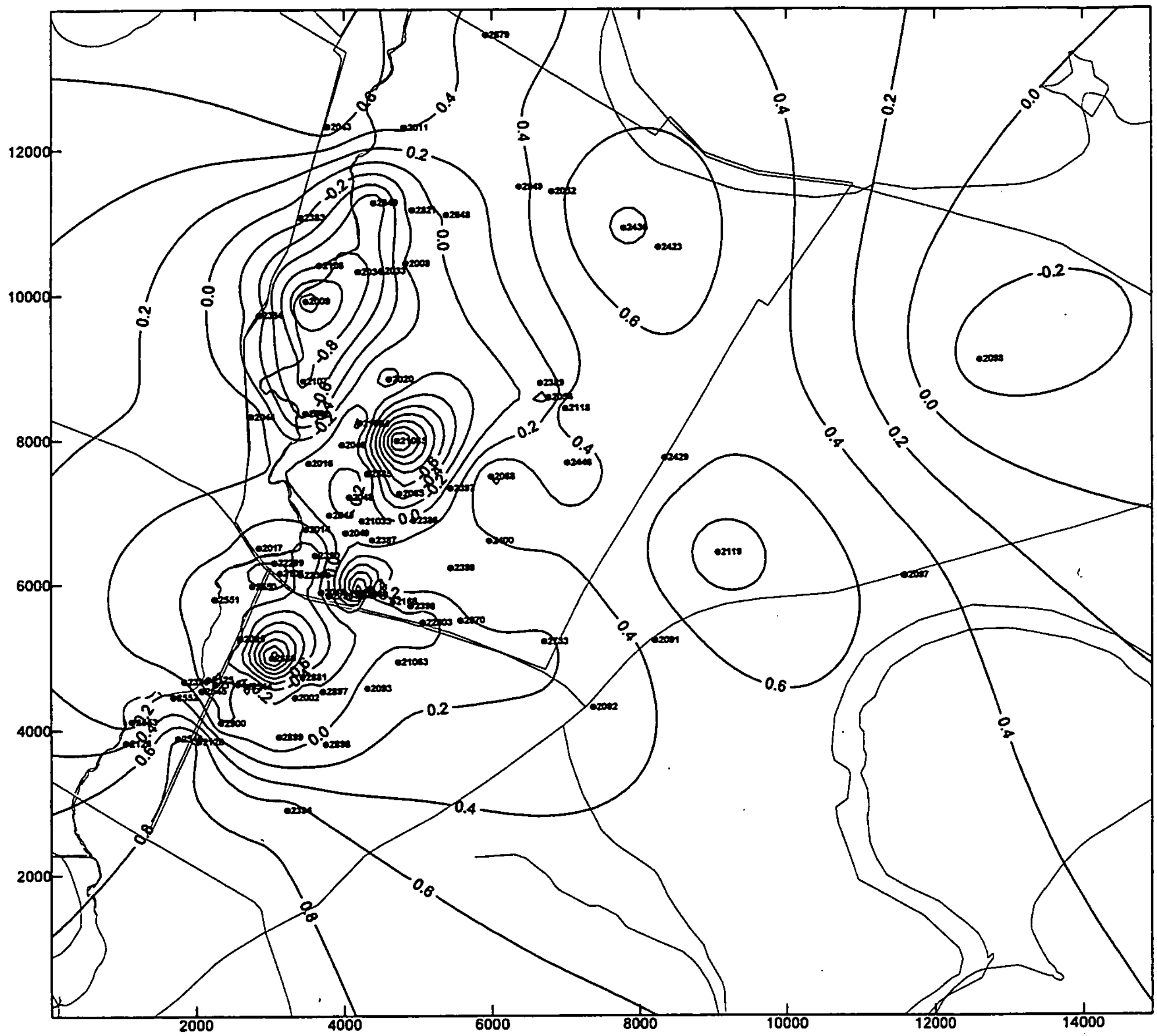

FIGURE D-3 RESIDUALS BETWEEN SIMULATED AND MEASURED WATER ELEVATIONS AT END OF JULY 1998 VALIDATION PROCEDURE.

D.3 VALIDATION FOR LOW AQUIFER WATER ELEVATIONS, OCTOBER 1999

Due to drought conditions through much of 1999, water levels measured during the October 1999 quarterly sampling were considerably lower than the October 1998 data that comprised the model flow calibration target. The October 1999 data set consists of measured water elevations that are lower than at any time within the previous several years. Due to the generally quiescent conditions preceding data collection, it was anticipated that the fit between modeled and measured water elevations would be similar to that of the October 1998 calibration and the July 1998 validation.

D.3.1 VALIDATION TARGET

As mentioned above, October 1999 water elevation measurements indicate lower water levels than at any time in the previous several years. It is anticipated that a model validated with this data will provide useful bounding predictions under the assumption of low water elevations for extended future periods. It was also assumed that good validation results with this data would demonstrate the robustness of the recalibrated model. Figure D.4 is a contour plot of the October 1999 validation target. The validation data set is included in Table D.5.

D.3.2 VALIDATION CRITERIA

The same criteria were used as for the April 1998 validation, described in Section 4.2. However, it was assumed that lower RMS errors would be attainable due to the apparent absence of significant transient water table features.

D.3.3 OBJECTIVE FUNCTION DEFINITION AND EVALUATION

As in the recalibration and initial validation exercises, the RMS error was used as the objective function. Incremental changes were made to boundary condition parameters until significant reductions in RMS error were no longer observed.

D.3.4 AQUIFER PUMPING/RE-INJECTION AND RESULTS FOR INITIAL OCTOBER 1999 VALIDATION RUN

Aquifer pumping and re-injection conditions were the same in October 1999 as for the October 1998 calibration, which were described in Section 3.4 of the main report. Therefore, the October 1998 calibration simulation was used as the initial October 1999 validation simulation. A new objective function was evaluated using the October 1999 validation target data. The initial RMS error was 3.12 feet and RMS percent error was 30.1 percent. This high initial error was attributed to the use of specified heads from the calibrated model, which reflect the higher groundwater elevations prevalent in October 1998.

D.3.5 OCTOBER 1999 VALIDATION SIMULATIONS

A single validation iteration, in which all boundary and river heads were lowered by 3 feet, was found to lower the RMS error to 0.45 feet (4.4 percent) – lower than the error achieved in the final July 1998 validation. Six well residuals were found to exceed 1 foot, but five of these had magnitudes of 1.12 feet or lower. Once again, most of the high-residual wells were at or near the extraction and injection system wells. These included well numbers 2049, 2544, 22299, and 22300. Residuals at these wells were investigated by examining daily reported extraction and re-injection system pumping rates over a period (October 17-21, 1999) during which the groundwater elevation measurements were taken. Table D.4 summarizes individual well rates by day over this period and notes the date of measurement at the four monitoring wells.

The "Target Rate" column in the table lists desired rates for extraction system pumping, which were also the rates specified in model simulations for this period. Table D-4 shows that considerable fluctuation in pumping and injection rates occurred during the sampling period, with rates generally well above targets on October 17 and 18, well below targets October 19 and 20, and back above targets on October 21. Based on the data in Table D-4, three more validation runs were performed. The runs implemented the following steps in order:

1. Decrease the South Plume Extraction well rates from target values to values for October 19 from Table D-4.
2. Changed South Plume Extraction, South Field Extraction and Injection rates to average values from the period October 17 to 21, 1999.
3. Subtracted 0.14 feet from all specified boundary and river heads.

The RMS error after these three steps was reduced to 0.42 ft (4.1 percent). Residuals between modeled and measured water elevations exceeded 1 foot at only five wells. As no further improvement in RMS errors could be achieved, these were taken as final validated values. However, it should be noted that field-measured well pumping and injection rates were used to make slight improvements in the model fit. Such information is not available for forecasting with the model, and target rates should be used.

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TABLE D-4

DAILY SUMMARY OF EXTRACTION/INJECTION SYSTEM PUMPING RATES DURING OCTOBER 1999 VALIDATION DATA SAMPLING PERIOD

			Oct. 17 1999	Oct. 18 1999	Oct. 19 1999	Oct. 20 1999	Oct. 21 1999
Monitoring Wells Sampled				2049, 22300	22299	2544	
Extraction/ Injection System	**Well #**	**Target Rate (gpm)**			**Pumping Rates (gpm)**		
South Plume	RW-1	300	319	326	248	291	314
	RW-2	300	324	326	241	279	296
	RW-3	400	402	413	301	364	372
	RW-4	500	503	519	378	447	617
	RW-6	250	266	276	207	240	252
	RW-7	250	263	275	209	241	253
South Field Extraction	EW-13	200	192	238	199	145	206
	EW-14	200	190	240	197	144	141
	EW-15	0	0	0	0	0	0
	EW-16	200	188	[illegible]	[illegible]	[illegible]	[illegible]
	EW-17	100	97	117	94	90	104
	EW-18	100	108	113	99	91	103
	EW-19	100	108	113	99	90	105
	EW-20	100	110	112	98	89	104
	EW-21	200	211	224	199	178	207
	EW-22	300	288	345	285	251	306
South Field Injection	IW-8	200	214	215	164	196	205
	IW-9	200	183	229	192	171	209
	IW-10	200	185	228	190	170	205
	IW-11	200	206	232	198	176	209
	IW-12	200	204	230	195	171	208

Final validated heads and head residuals for October 1999 are presented in Figures D.5 and D.6. Final RMS and RMS percent errors were 0.42 feet and 4.1 percent, respectively. For the final validation, a complete listing of predicted and observed elevations at each monitoring well in the validation target set is included in Table D.5. Table D.6 contains a description and summary of error statistics for each of the October 1999 validation runs.

TABLE D-5

SUMMARY OF OBSERVED AND CALCULATED HEADS, PREDICTION RESIDUALS, AND ERROR STATISTICS, OCTOBER 1999 VALIDATION.

10/99 VALIDATION RESULTS

HEADS IN FEET ABOVE MSL

ID	OBS	CALC	RESID	% ERROR
80	513.42	512.39	-1.03	-10.0
2002	511.09	511.02	-0.07	-0.7
2009	518.95	518.61	-0.34	-3.3
2015	514.53	514.33	-0.20	-1.9
2016	514.98	515.61	0.63	6.1
2017	515.54	515.53	-0.01	-0.1
2020	516.45	516.62	0.17	1.7
2027	517.71	517.93	0.22	2.1
2032	518.89	518.66	-0.23	-2.2
2033	518.30	518.07	-0.23	-2.2
2034	518.61	518.37	-0.24	-2.3
2043	519.34	520.31	0.97	9.3
2044	517.37	517.79	0.42	4.0
2045	514.47	514.62	0.15	1.5
2046	516.12	515.97	-0.15	-1.5
2048	514.90	514.93	0.03	0.3
2049	513.45	514.54	1.09	10.5
2051	514.59	514.64	0.05	0.5
2052	516.87	517.28	0.41	4.0
2065	515.29	514.51	-0.78	-7.5
2068	515.00	514.92	-0.08	-0.8
2070	514.17	514.05	-0.12	-1.1
2091	513.98	513.77	-0.21	-2.0
2092	514.05	513.63	-0.42	-4.0
2093	512.96	512.84	-0.12	-1.2
2095	513.00	513.00	0.00	0.0
2096	518.37	518.98	0.61	5.8
2097	511.56	512.27	0.71	6.8
2106	514.92	515.00	0.08	0.8
2107	517.77	517.60	-0.17	-1.6
2108	519.18	518.98	-0.20	-2.0
2119	513.39	513.84	0.45	4.3
2125	512.01	512.16	0.15	1.4
2126	511.16	511.37	0.21	2.0
2166	514.29	514.18	-0.11	-1.1
2383	519.64	519.78	0.14	1.3
2385	515.14	515.21	0.07	0.7
2386	514.47	514.27	-0.20	-2.0
2387	514.34	514.23	-0.11	-1.1
2390	515.11	514.71	-0.40	-3.9
2394	509.26	509.87	0.61	5.9
2396	512.56	512.71	0.15	1.4
2397	514.90	514.73	-0.17	-1.7

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TABLE D-5

(Continued)

2398	513.59	514.23	0.64	6.2
2399	514.26	514.30	0.04	0.3
2400	514.41	514.45	0.04	0.3
2402	517.32	517.01	-0.31	-3.0
2417	514.68	514.68	0.00	0.0
2423	515.30	515.66	0.36	3.5
2424	514.51	514.68	0.17	1.6
2426	514.55	514.61	0.06	0.5
2429	514.48	514.47	-0.01	-0.1
2430	514.59	514.56	-0.03	-0.3
2431	514.41	514.36	-0.05	-0.5
2432	514.24	514.16	-0.08	-0.7
2434	514.46	514.23	-0.23	-2.3
2436	515.74	516.15	0.41	4.0
2446	515.05	514.85	-0.20	-1.9
2544	512.76	511.20	-1.56	-15.0
2545	[illegible]	[illegible]	[illegible]	[illegible]
2546	510.84	511.18	0.34	3.2
2550	514.67	514.72	0.05	0.5
2552	512.42	512.53	0.11	1.1
2553	512.02	512.21	0.19	1.9
2648	517.94	518.04	0.10	0.9
2649	518.87	519.09	0.22	2.1
2679	519.34	519.59	0.25	2.4
2702	509.67	510.07	0.40	3.8
2733	514.27	513.91	-0.36	-3.5
2821	518.40	518.49	0.09	0.8
2880	512.12	511.84	-0.28	-2.7
2881	512.18	511.92	-0.26	-2.5
2897	512.36	512.05	-0.31	-3.0
2898	511.76	511.24	-0.52	-5.0
2899	510.65	510.39	-0.26	-2.5
2900	510.88	510.70	-0.18	-1.7
21033	514.47	514.53	0.06	0.6
21063	513.48	513.47	-0.01	-0.1
21064	515.91	516.22	0.31	3.0
21065	515.57	515.63	0.06	0.6
21194	511.71	511.72	0.01	0.1
22198	514.60	514.72	0.12	1.2
22299	514.57	515.63	1.06	10.2
22300	516.09	514.95	-1.14	-10.9
22301	515.09	514.48	-0.61	-5.9
22302	515.06	514.25	-0.81	-7.8
22303	514.96	514.31	-0.65	-6.3

AVG RESID = -0.01 FEET
RMS ERROR = 0.42 FEET
RMS % ERROR = 4.09

TABLE D-6

RUN DESCRIPTIONS AND ERROR STATISTICS FOR OCTOBER 1999 VALIDATION SIMULATIONS.

Name	Description	Mean Error (ft)	RMS Error (ft)	RMS Percent Error
FL3VAL00	Initial run, same as 10/98 calibration	3.09	3.12	30.08
FL3VAL01	Same as run 00 except subtracted 3 feet from all boundary and river heads	0.02	0.45	4.38
FL3VAL02	Same as run 01 except reduced South Plume Extraction rates as per 10/19/99 data	0.35	0.53	5.11
FL3VAL03	Same as run 01 except changed all pumping and injection rates as per 10/17 – 10/21 averages	0.13	0.44	4.28
FL3VAL04 (validated)	Same as run 03 except subtracted 0.14 feet from all boundary and river heads	-0.01	0.42	4.09

000073

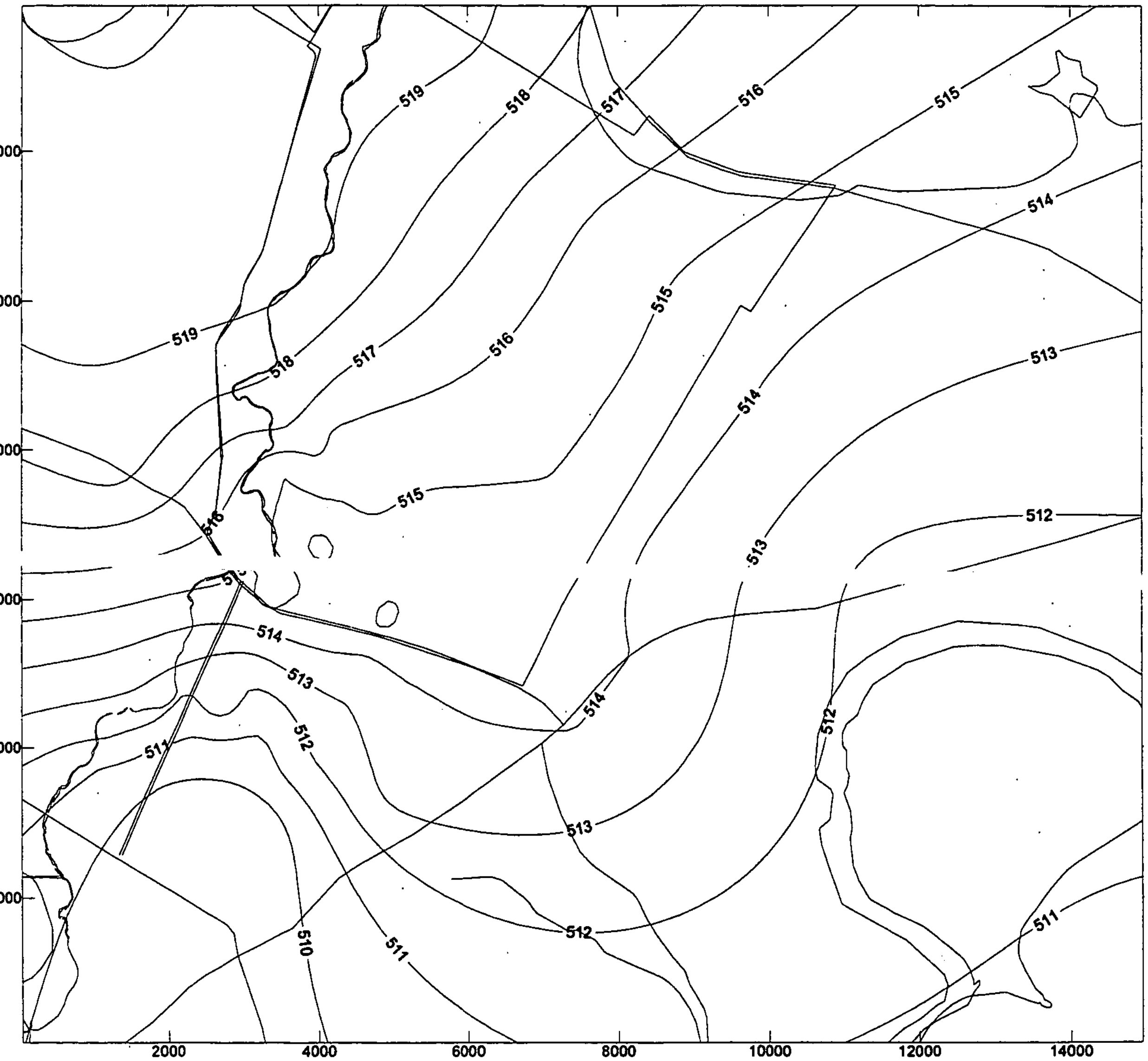

FIGURE D-4 VALIDATION TARGET – CONTOURED WATER ELEVATION DATA FROM OCTOBER, 1999.

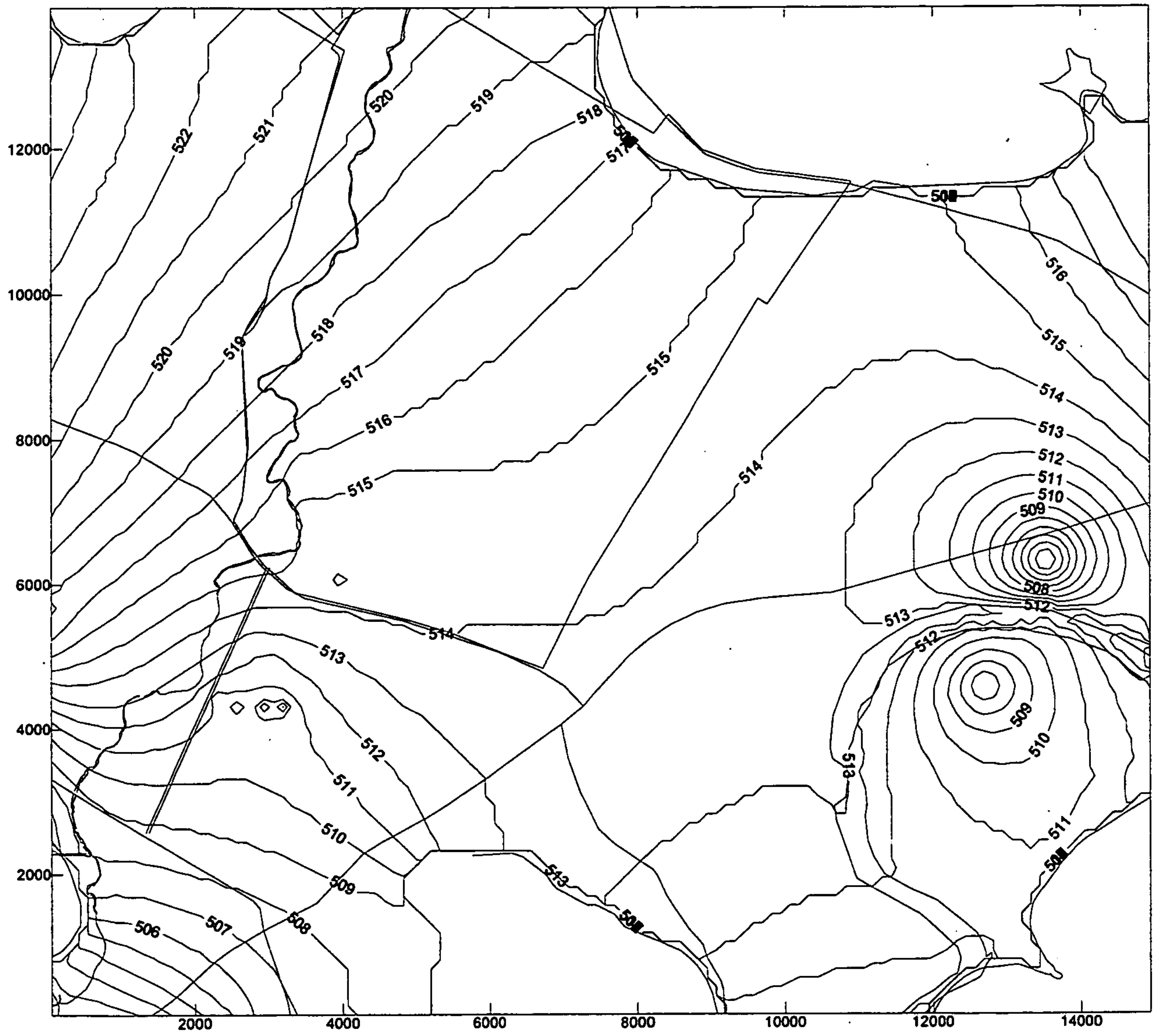

FIGURE D-5 SIMULATED WATER TABLE AT END OF OCTOBER 1999 VALIDATION PROCEDURE.

000075

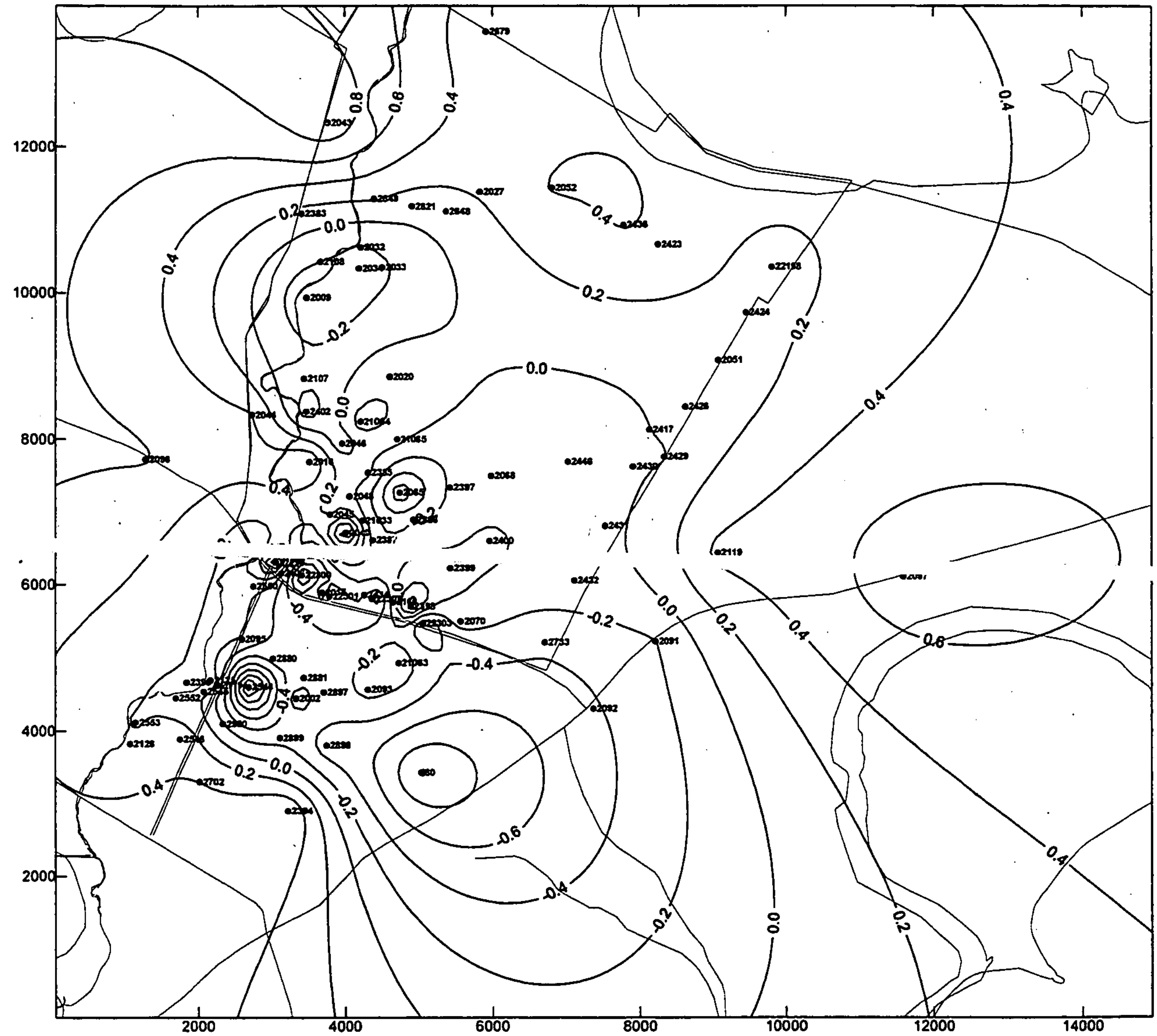

FIGURE D-6 RESIDUALS BETWEEN SIMULATED AND MEASURED WATER ELEVATIONS AT END OF OCTOBER 1999 VALIDATION PROCEDURE.